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SHORT-TIME TENSILE PROPERTIES OF THE
Co-20Cr-15W-10Ni COBALT-BASE ALLOY (L-605)

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SHORT-TIME TENSILE PROPERTIES OF THE Co-20Cr-15W-10Ni COBALT-BASE ALLOY (L-605)

by

C. J. Slunder*

INTRODUCTION

The alloy Co-20Cr-15W-10Ni known commercially as Haynes Alloy No. 25, and also as L-605 and WF-11 and covered by Aeronautical Material Specifications AMS5537B (sheet) and AMS5759B (bar), is a cobalt-base alloy having good high-temperature mechanical properties and good ductility at room temperature. It is easily machined and cold formed, and can be welded and brazed by various processes. These properties, combined with good resistance to oxidation and carburization, have made the alloy useful in many high-temperature applications.

The standard mechanical properties of the alloy have been reported by producers in their information bulletins. Generally, typical or average values are given in such publications. Some data are also available from users of the alloy who measured mechanical properties to check specifications, or in connection with development programs. In recent years, these data were not enough to meet the needs of designers of advanced aerospace vehicles and propulsion systems. The mechanical properties of materials under severe and unusual conditions had to be investigated. Therefore, a number of programs to obtain such information under conditions simulating those expected in service have been undertaken. Mechanical-property data have been obtained for potentially useful alloys under such conditions as cryogenic temperatures, temperatures near the melting point, rapid loading and heating, and thermal cycling. Also, the effects of brazing and welding on the properties have been studied.

The results of these investigations have been published in numerous reports. These may not all be quickly available to prospective users of an alloy. Furthermore, many of the reports contain data for more than one alloy, and gathering the data from such sources for any one material is time consuming and not always practical.

In view of the interest in the Co-20Cr-15W-10Ni alloy, it appeared desirable to assemble into one document the information on the mechanical properties of the alloy from reports and other literature in the files of the Defense Metals Information Center.

In this memorandum, data have been selected, covering only the short-time tensile properties of Co-20Cr-15W-10Ni. These data have been assembled under four general headings:

- (1) Room-temperature tensile properties
- (2) Short-time elevated-temperature tensile properties
- (3) Tensile properties of welded and brazed joints
- (4) Tensile properties at cryogenic temperatures.

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Because many of the reports examined contained data on several mechanical properties, it was not always feasible to put every piece of data under a strictly appropriate heading. For example, practically all of the tabulations of short-time elevated-temperature properties also include some information at room temperature for comparison purposes. Such data were left in the high-temperature tabulations.

In most cases, the data are reproduced as reported by the original authors. However, an attempt was made to attain some measure of uniformity by using the same units in all of the tables and figures. Appropriate changes were made where necessary without interfering with the reported values for the mechanical properties. Also, some graphs were replotted and new tabulations made using only data applicable to Co-20Cr-15W-10Ni to avoid confusion with information applicable to other alloys.

This memorandum is simply a compendium of reported data, not an evaluation of the alloy reported on. It should be noted that some of the results recorded are typical values. Others are the product of a limited number of tests. Therefore, original sources may need to be consulted before the data are used for other than comparative purposes. Each group of data is identified by a number which refers to the original source of the data. A tabulation of these references is included at the end of the memorandum.

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TABLE 1. AMS COMPOSITION SPECIFICATION FOR COBALT-BASE 20Cr-10Ni-15W ALLOY

Sheet - Reference 1; bar - Reference 2.

Material, %	Check Analysis	
	Under Min, %	Over Max, %
Carbon, 0.05 - 0.15	0.01	0.01
Manganese, 1.00 - 2.00	0.04	0.04
Silicon, 1.00 max	--	0.05
Phosphorus, 0.040 max	--	0.005
Sulfur, 0.030 max	--	0.005
Chromium, 19.00 - 21.00	0.25	0.25
Nickel, 9.00 - 11.00	0.15	0.15
Tungsten, 14.00 - 16.00	0.10	0.10
Iron, 3.00 max	--	0.10
Cobalt, remainder		

TABLE 2. AMS TENSILE-PROPERTY SPECIFICATIONS
(Co-20Cr-15W-10Ni)

Sheet - Reference 1; bar - Reference 2.

<u>Sheet Material</u>	
Tensile Strength, psi	130,000 Min
Yield Strength at 0.2% Offset or at 0.0072 In. in 2 In. Extension Under Load ($E = 34,200,000$), psi	55,000 - 80,000
Elongation, % in 2 In. 0.020(a) and under	30 Min
0.020 to 0.032	35 Min
0.032 to 0.043	40 Min
Over 0.043	45 Min

For widths 9 in. and over, tensile-test specimens shall be taken with the axis perpendicular to the direction of rolling. For widths less than 9 in., tensile-test specimens shall be taken with the axis parallel to the direction of rolling.

Bar and Forgings

Specimens taken from bars and forgings, and from parent metal of flash-welded rings shall conform to the following requirements:

Tensile Strength, psi	125,000 Min
Yield Strength at 0.2% Offset or at 0.0066 In. in 2 In. Extension Under Load ($E = 34,200,000$), psi	45,000 Min
Elongation, % in 4D	30 Min

(a) Nominal thickness, in.

TABLE 3. TYPICAL ROOM-TEMPERATURE TENSILE PROPERTIES OF SHEET AND PLATE (Co-20Cr-15W-10Ni)

Reference 3.

Form and Condition(a)	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation in 2 In., %
Sheet, 0.044 to 0.056 in.	144.5 ^(b) 130.0 ^(c)	66.7 ^(b) 55.0 ^(c)	58.8 ^(b) 45.0 ^(c)
Sheet, 0.060 to 0.083 in.	139.1 ^(b) 130.0 ^(c)	62.2 ^(b) 55.0 ^(c)	62.2 ^(b) 45.0 ^(c)
Sheet, 0.094 to 0.130 in.	140.6 ^(b) 130.0 ^(c)	64.6 ^(b) 55.0 ^(c)	62.1 ^(b) 45.0 ^(c)
Sheet, 0.141 to plate, 0.313 in.	136.7 ^(b)	63.0 ^(b)	63.0 ^(b)
Plate, 0.375 to 0.625 in.	142.6 ^(b)	68.3 ^(b)	56.4 ^(b)
Plate, 0.750 in. and up	138.7 ^(b)	65.8 ^(b)	60.3 ^(b)

(a) Sheet, heat treated at 2250 F and rapid air cooled; plate, heat treated at 2250 F and water quenched

(b) Average properties.

(c) Guaranteed minimum properties.

TABLE 4. ROOM-TEMPERATURE TENSILE PROPERTIES.
0.050-IN. SHEET (Co-20Cr-15W-10Ni)

Reference 4.

Condition	Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation, %
Hot rolled	164.5	101.0	47.5
Annealed at 2225 F	152.8	71.7	62.8

TABLE 5. LONGITUDINAL AND TRANSVERSE ROOM-TEMPERATURE TENSILE
PROPERTIES (Co-20Cr-15W-10Ni)(a)

0.040-in. -thick annealed sheet.

Reference 5.

Direction(b)	Proportional Limit, ksi	0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Modulus of Elasticity, 10 ⁶ psi	Elongation, %
L	26.20	67.33	136.10	38.2	41.2
T	19.81	60.40	135.60	38.3	40.8

(a) Results are average of three determinations; strain rate, 0.00005 in./in./sec.

(b) L and T denote longitudinal and transverse with respect to rolling direction.

TABLE 6. ROOM-TEMPERATURE PROPERTIES OF AS-RECEIVED MATERIAL (Co-20Cr-15W-10Ni)

Testing done according to Federal Test Method 151 except that loads were applied at a strain rate of 0.005 ± 0.002 in./in./min to the 0.2% offset yield point.

Reference 6.

Nominal Gage, in.	Total Sheets(a)	Grain Direction(b)	Ultimate Strength, ksi			Yield Strength			Superficial Hardness, Rockwell 15 N
			Avg	Range	Low Deviation(c)	Avg	Range	Low Deviation(c)	
0.010	29	L	107.93	42.1	4.1	64.5	22.3	8.9	30.10-42.50
0.010		T	112.60	61.1	30.0	63.8	15.9	8.7	29.50-41.00
0.020	26	L	129.90	63.9	29.0	66.3	17.1	9.1	26.0-25.3
0.020		T	129.70	58.2	27.0	66.2	22.0	12.0	27.6-23.1
0.040	15	L	137.60	40.3	21.0	70.4	22.0	14.8	35.0-61.8
0.040		T	136.50	40.2	22.0	68.1	19.0	9.0	37.0-44.3
0.060	3	L	135.6	13.3	3.4	69.9	11.0	7.0	23.0
0.060		T	136.8	14.2	8.1	67.8	5.6	2.5	40.0
0.008	13	T	109.1	31.0	15.7	65.9	12.3	6.1	20.3
									62-66

(a) Material removed from each sheet or coil; two specimens for each direction of rolling.

(b) L - longitudinal; T - transverse.

(c) Represents lowest deviation from the average value.

TABLE 7. ROOM-TEMPERATURE TENSILE PROPERTIES OF SHEET
(Co-20Cr-15W-10Ni)

Reference 7.

Heat	Sheet Gage, in.	Direction(a)	Ultimate Tensile Strength, ksi(b)	0.2% Offset Yield Strength, ksi(b, c)	Modulus, 10 ⁶ psi(b)	Elongation in 2 In., %
A	0.020	L	148.3(9)	76.9(9)	37.7(9)	51.8(9)
B	0.020	L	139.0(10)	69.6(10)	33.3(10)	49.0(10)
C	0.020	L	141.9(8)	73.4(8)	33.4(8)	48.4(8)
A	0.020	T	148.1(9)	73.2(9)	36.9(9)	48.7(7)
B	0.020	T	146.2(10)	68.7(10)	35.5(10)	48.5(10)
C	0.020	T	150.2(10)	73.9(10)	36.6(10)	45.8(10)
A	0.040	L	137.8(10)	70.3(10)	33.8(10)	55.2(10)
B	0.040	L	141.6(5)	72.4(5)	32.7(5)	53.1(5)
C	0.040	L	142.4(5)	72.1(5)	33.1(5)	53.2(5)
A	0.040	T	137.9(10)	66.5(10)	32.6(10)	53.1(10)
B	0.040	T	139.1(5)	66.3(5)	33.1(5)	51.9(5)
C	0.040	T	141.8(5)	67.9(5)	32.7(5)	50.8(5)

(a) L - longitudinal; T - transverse.

(b) Results reported are the averages of the number of tests noted in parentheses.

(c) Strain rate of 0.005 in./in./min to the yield point, then crosshead speed 0.06 in./min to fracture.

TABLE 8. ROOM-TEMPERATURE TENSILE PROPERTIES - EFFECT OF
HEAT TREATMENT AND GRAIN DIRECTION
(Co-20Cr-15W-10Ni)

Strain rate 0.02 in./in./min to the yield, then 0.08 in./in./min
to fracture.

Reference 8.

Gage, in.	Condition	Grain Direction	Ultimate Tensile Strength, ksi	Yield Strength, ksi	Elongation in 2 In., %	Hardness, Rockwell C
0.040	As received	L(a)	146.5(b)	69.1(b)	55(b)	19(b)
0.040	As received	T	139.9(c)	64.2(c)	--	19(c)
0.125	As received	L	149.7(d)	76.2(d)	56(d)	24(d)
0.125	As received	T	151.0(c)	71.4(c)	54(c)	25(c)
0.040	Heat treated(e)	L	138.2(d)	63.9(d)	54(d)	15(d)

(a) L - longitudinal; T - transverse.

(b) Average of eight tests.

(c) Average of three tests.

(d) Average of five tests.

(e) Double annealed at 2250 ± 25 F in air for 10 min, air quenched, and pickled.

TABLE 9. ROOM-TEMPERATURE TENSILE PROPERTIES OF 0.063-IN. SHEET WITH VARIOUS NUMBERS OF SIMULATED IN-PROCESS ANNEALS (Co-20Cr-15W-10Ni)

Reference 9 - Section A. 12. 4.

Number of Anneals	20-Min-Anneal Temperature, F	Ultimate Strength, ksi	0.02% Yield Strength, ksi	0.2% Yield Strength, ksi	Elongation, %
None	2250	142.1	45.9	64.5	60.5
None	2250	141.4	45.5	64.3	62.0
None	2250	142.0	47.0	66.9	57.5
None	2250	141.8	47.5	66.5	60.5
1	2250	138.5	52.8	64.4	62.0
1	2250	138.5	55.1	65.5	61.0
1	2250	140.8	52.5	66.2	62.0
1	2250	136.2	50.5	66.3	50.5
3	2250	137.9	54.9	64.3	53.5
3	2250	134.3	50.5	62.4	57.0
3	2250	129.5	50.2	62.1	51.5
3	2250	127.4	49.7	59.9	51.5
5	2250	124.4	49.4	58.6	44.0
5	2250	131.2	47.1	60.8	48.0
5	2250	129.0	48.6	60.5	55.0
5	2250	126.3	46.9	59.4	58.0

(a) Cleaned by Virgo process after heat treatments.

TABLE 10. ROOM-TEMPERATURE TENSILE PROPERTIES,
SHEET OF VARIOUS THICKNESSES
(Co-20Cr-15W-10Ni)

Solution heat treated; specimens loaded perpendicular to grain direction at 0.005 in./in./min to the yield, then 0.030 in./in./min.

Reference 10.

Specimen Thickness, in.	Yield Strength, ksi	Ultimate Strength, ksi	Elongation in 2 In., %
0.0085	68.8	125.0	25
0.0085	73.5	122.5	29
0.0085	67.5	127.5	30
0.033	67.8	130.6	28
0.033	70.3	140.0	41
0.033	70.6	140.0	38
0.069	64.9	145.7	49
0.069	66.3	144.7	51
0.069	65.7	143.6	41
0.070	68.0	147.7	55
0.070	67.9	148.3	56
0.070	69.3	146.1	53
0.126	67.1	129.8	33
0.127	66.4	138.4	41
0.126	67.8	138.7	42

TABLE 11. ROOM-TEMPERATURE PROPERTIES OF ANNEALED
0.005-IN. FOIL (Co-20Cr-15W-10Ni)

Reference 11.

Tensile Strength, ksi	Yield Strength, ksi	Elongation in 2 In., %	Apparent Modulus of Elasticity, 10^6 psi
136.5	84.5	22.0	31.8
136.5	84.5	20.0	30.4
130.0	87.0	16.0	31.5
139.0	85.9	20.0	30.9
135.2	84.9	18.0	30.8
141.5	85.0	20.0	30.2
134.0	84.4	20.0	29.3
131.8	82.9	18.0	30.6
136.0	82.3	18.0	31.3
Average			
135.6	84.6	19.0	30.7

TABLE 12. ROOM-TEMPERATURE TENSILE PROPERTIES OF
1-IN. PLATE (Co-20Cr-15W-10Ni)^(a)

Reference 7.

Heat	Direction ^(b)	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength ^(c) , ksi	Modulus, 10 ⁶ psi	Elongation in 2 In., %
A	L	141.4	70.6	33.8	58.7
B	L	142.2	69.3	34.6	56.0
C	L	141.0	69.8	34.0	54.5
C	T	140.7	69.9	34.4	55.0

(a) Results are averages of ten tests for each condition.

(b) L - longitudinal; T - transverse.

(c) Strain rate of 0.005 in./in./min to the yield point, then crosshead speed of 0.060 in./min to fracture.

TABLE 13. UNIFORM ELONGATION OF SHEET AT ROOM
TEMPERATURE (Co-20Cr-15W-10Ni)^(a)

Reference 10.

Gage, in.	Loading Rate, in./min	Failing Stress, ksi	Uniform Elongation, %	Total Elongation, %
0.010	25	105.0	13.1	14.1
0.010	25	105.6	16.7	19.6
0.010	25	105.6	12.2	12.5
0.036	4	126.5	25.8	26.1
0.036	4	120.9	23.0	23.0
0.036	4	121.5	23.2	24.3
0.070	4	145.8	47.4	48.4
0.070	4	145.8	44.2	45.9
0.070	4	145.1	41.6	41.9
0.125	4	128.3	37.6	37.6
0.125	4	127.2	34.5	34.5
0.125	4	132.1	39.0	39.0

(a) Sixteen-in. specimens, eight-in. gage length.

TABLE 14. ROOM-TEMPERATURE TENSILE PROPERTIES OF .005-IN.
FOIL AFTER EXPOSURE TO CONDITIONS SHOWN
(Co-20Cr-15W-10Ni)^(a)

Reference 11.

Exposure Temperature, F	Exposure Time, hr	Atmosphere	Tensile Strength, ksi	Yield Strength, ksi	Elongation in 2 in.,
2000	1	Air	133.9	72.4	21.4
2000	1	Argon	153.0	70.8	20.0
2000 ^(b)	24	Air	64.4	49.7	3.0
2000	24	Argon	155.5	66.9	25.6
2200	1	Air	113.4	64.8	29.6
2200	1	Argon	137.9	61.4	43.6
2200	24	Air	Completely oxidized		
2200	24	Argon	101.5	54.6	24.8

(a) Average of five tests except as indicated.

(b) Average of two tests.

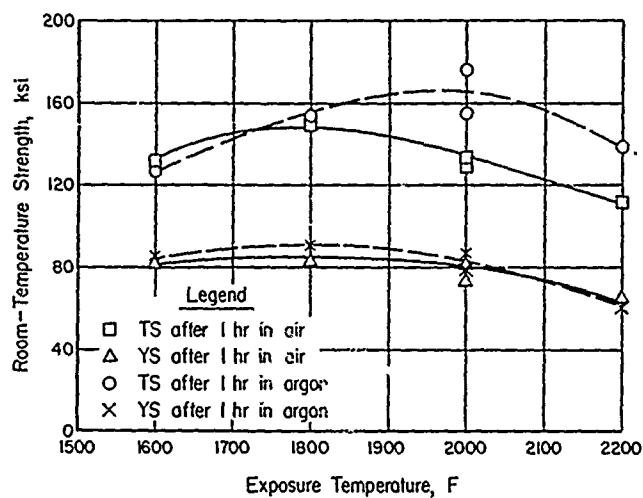


FIGURE 1. ROOM-TEMPERATURE TENSILE AND YIELD STRENGTHS AFTER 1 HR EXPOSURE AT ELEVATED TEMPERATURES (Co-20Cr-15W-10Ni)

0.005-in.-thick foil.

Reference 11.

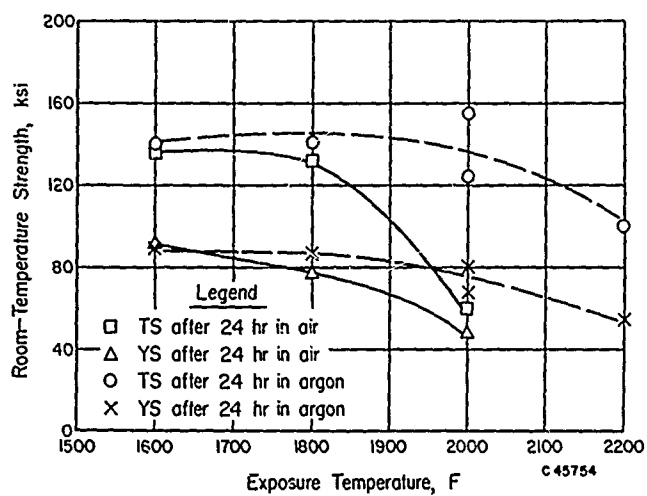


FIGURE 2. ROOM-TEMPERATURE TENSILE AND YIELD STRENGTHS AFTER 24-HR EXPOSURE AT ELEVATED TEMPERATURES (Co-20Cr-15W-10Ni)

0.005-in.-thick foil.

Reference 11.

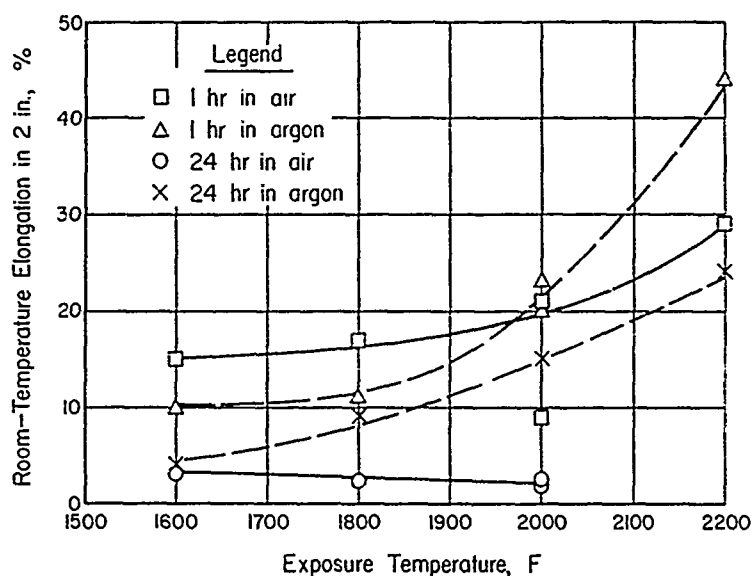


FIGURE 3. ROOM-TEMPERATURE ELONGATION AFTER EXPOSURE TO AIR OR ARGON AT ELEVATED TEMPERATURES (Co-20Cr-15W-10Ni)

0.005-in.-thick foil.

Reference 11.

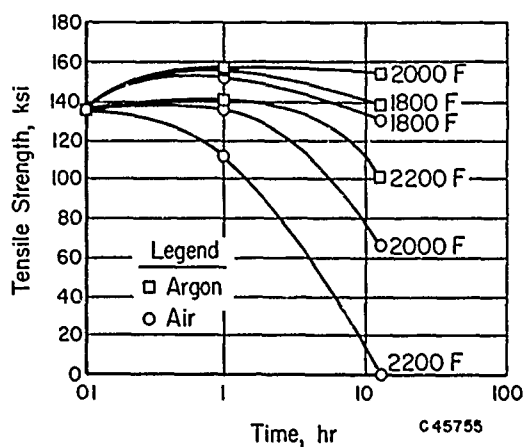


FIGURE 4. EFFECT OF ATMOSPHERE AND EXPOSURE TIME AND TEMPERATURE ON THE ROOM-TEMPERATURE STRENGTH OF 0.005-IN. FOIL (Co-20Cr-15W-10Ni)

Reference 11.

TABLE 15. ROOM-TEMPERATURE TENSILE PROPERTIES OF SHEET
AFTER 1000 HR AT 1600 F (Co-20Cr-15W-10Ni)

One-in. -gage-length specimens tested at 0.005 in. /in. /min.

Reference 9 - Section A.6.

Heat(a)	Ultimate Tensile Strength, ksi	Yield Strength		Elongation, %
		0.2% Offset, ksi	0.02% Offset, ksi	
A	162.0(b)	85.2(b)	56.5(b)	9(b)
B	150.0	76.6	51.5	7
C	155.0	82.3	59.8	5
D	153.0	84.6	64.3	5
E	142.0	81.7	60.5	5
F	132.3	76.8	55.4	2
G	133.0(b)	91.2(b)	62.5(b)	1(b)

(a) Heats A through F, 0.063-in. sheet; Heat G, 0.160-in. sheet.

(b) Average of two or more determinations.

TABLE 16. ROOM-TEMPERATURE TENSILE PROPERTIES OF 0.020-IN. SHEET AFTER CYCLIC THERMAL EXPOSURE (Co-20Cr-15W-10Ni)

Five min to heat and stabilize before load was applied. Strain rate 0.002 in. /in. /min to the yield, then 0.03 in. /in. /min to failure.

Reference 6.

Exposure		Number of Cycles(a)	Test Temperature, F	Ultimate Strength, ksi	0.2% Offset	
Temperature, F	Time, hr				Yield Strength, ksi	Elongation in 2 In., %
1600	1	1	70	112.3	70.4	18.0
1600	1	1	70	129.7	71.2	34.5
1600	1	5	70	121.1	69.2	22.0
1600	1	5	70	100.3	70.8	10.5
1600	1	10	70	112.5	71.1	13.5
1600	1	10	70	120.3	69.9	18.0
1800	1	1	70	127.1	--	31.0
1800	1	1	70	126.1	--	31.0
1800	1	5	70	139.4	64.0	--
1800	1	5	70	138.6	69.9	22.0
1800	1	10	70	140.3	70.1	14.5
1800	1	10	70	141.3	72.1	13.0
2000	1	1	70	127.3	59.9	34.0
2000	1	1	70	129.2	62.0	34.5
2000	1	5	70	126.8	56.4	25.5
2000	1	5	70	128.1	56.3	26.5
2000	1	10	70	105.3	51.3	18.0
2000	1	10	70	105.1	50.0	16.0
2200	1	1	70	112.7	49.5	44.0
2200	1	1	70	108.6	44.2	46.0
2200	1	5	70	87.7	43.6	47.0
2200	1	5	70	85.0	42.5	35.5
2200	1	10	70	70.6	44.1	21.0
2200	1	10	70	51.4	35.2	--
2200	1	1	70	65.6	45.9	18.5
2200	1	1	70	72.6	45.5	23.5

(a) Cycles between room temperature and exposure temperature.

TABLE 17. ROOM-TEMPERATURE MECHANICAL PROPERTIES OF AGED SHEET (Co-20Cr-15W-10Ni)(a)

Reference 12.

Aging Condition		Ultimate	0.2% Offset	Elongation in 2 In. , %	Hardness, Rockwell C
Temperature, F	Time, hr	Tensile Strength ^(b) , ksi	Yield Strength, ksi		
1400	4	138.0	69.5	50	27
		136.0	70.0	43	27
	8	134.5	70.8	38	27
		136.5	71.8	38	28
	16	134.5	71.5	34	28
		135.0	70.8	32	28
	32	130.0	70.7	26	30
		126.5	70.6	25	29
	64	127.0	73.0	20	28
		129.5	72.8	22	28
	4	122.0	69.3	18	29
		126.5	69.0	20	29
1650	8	128.0	71.0	14	32
		123.5	72.0	12	31
	16	138.5	77.2	10	34
		141.0	75.8	10	35
	32	146.0	84.7	6	38
		144.0	77.7	7	38
	64	153.0	82.3	6	40
		145.0	81.3	4	40
	4	136.0	72.2	17	32
		135.5	70.5	16	32
	8	137.5	72.0	10	36
		138.0	72.2	10	35
1800	16	149.0	74.0	10	35
		151.0	74.2	11	37
	32	147.5	73.7	11	38
		146.5	73.4	11	37
	64	147.5	74.0	10	37
		150.0	74.0	11	37

(a) 0.109- or 0.125-in. sheet.

(b) Crosshead speed, 0.05 in./min through the yield, then 0.5 in./min.

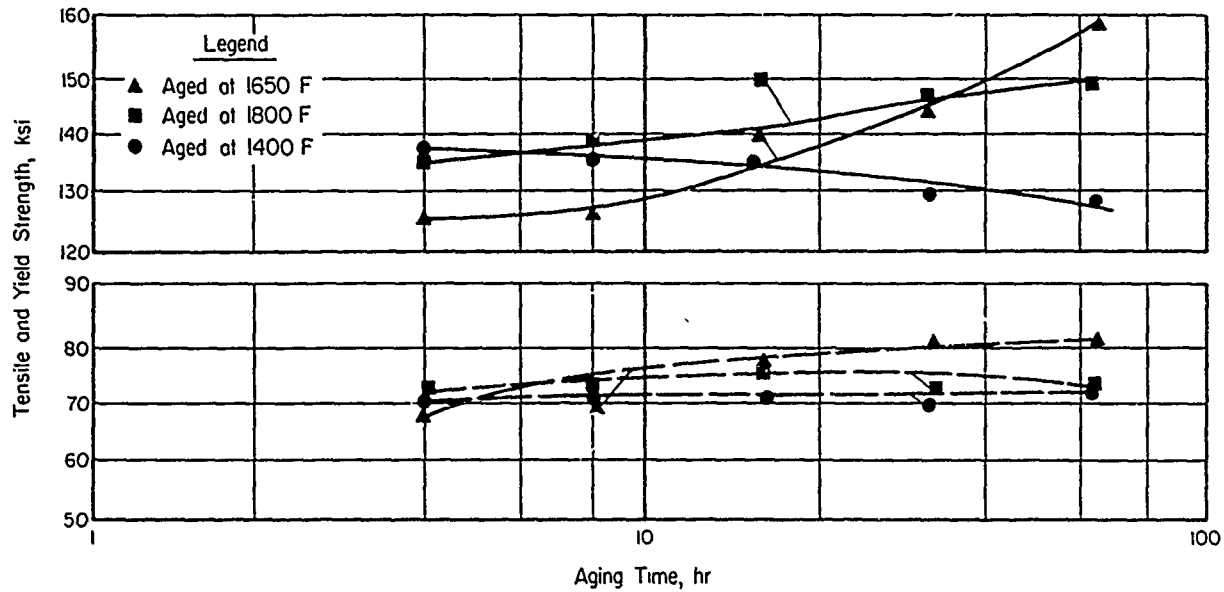


FIGURE 5. EFFECT OF AGING ON THE ROOM-TEMPERATURE TENSILE AND YIELD STRENGTHS (Co-20Cr-15W-10Ni)

0.109- or 0.125-inch sheet.

Reference 12.

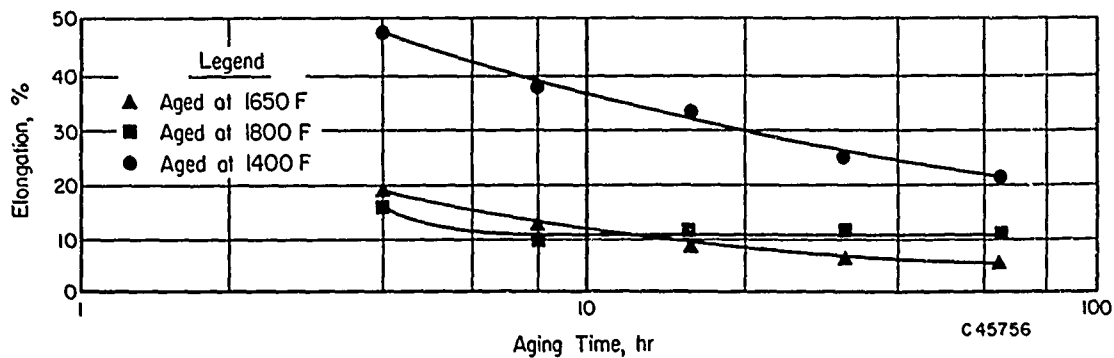


FIGURE 6. EFFECT OF AGING ON ROOM-TEMPERATURE ELONGATION (Co-20Cr-15W-10Ni)

0.109- or 0.125-inch sheet.

Reference 12.

TABLE 18. EFFECT OF SHEAR FORMING ON THE ROOM-TEMPERATURE TENSILE PROPERTIES
(Co-20Cr-15W-10Ni)(a)

Original material 0.150-in. sheet, solution heat treated. Strain rate - 0.005 in./in./min through the yield, then 0.05 in./in./min.

Reference 13.

Condition(b)	Direction	Ultimate Tensile Strength(c), ksi	0.2% Offset Yield Strength(c), ksi	Elongation in 2 in. (c), %	Hardness(c, d), Rockwell
Solution treated	L	134.4	67.7	52.5	B 96.1
Solution treated	T	131.3	62.0	40.0(e)	B 95.1
20% reduction	R(a)	184.8	155.6	11.7	C 43.6
30% reduction	R	219.6	191.3	3.0	C 45.2
40% reduction	R	234.8	201.4	1.7	C 47.5
50% reduction(f)	R	269.7	266.4	1.0	C 49.7
20% reduction and age	R	199.1	178.3	1.8	C 45.0
30% reduction and age(g)	R	226.3	223.9	1.8	C 49.0
40% reduction and age	R		Too brittle to test		C 52.5
50% reduction and age	R		Too brittle to test		C 54.6
Solution treat and age	L	131.1	63.0	68.0	B 94.5
Solution treat and age	T	132.3	63.2	65.3	B 94.5
20% reduction and solution treat and age	R	135.1	60.3	62.2	B 94.3
30% reduction and solution treat and age	R	133.4	60.4	62.8	B 94.5
40% reduction and solution treat and age	R	137.8	68.9	61.5	B 94.8
50% reduction and solution treat and age	R	136.9	64.8	59.8	B 95.4

(a) Original sheet formed into cones with one pass of the roller. Tensile specimens had long axis parallel to radial lines of the cone. They were curved in the width direction, and special jaws were used.

(b) Solution treatment, 2250 ± 25 F, rapid air cool; age at 1100 ± 25 F for 16 hr, air cool.

(c) Average of three specimens, except as noted.

(d) Hardness measurements before tensile testing.

(e) Broke at end of gage length.

(f) One test.

(g) Two tests.

TABLE 19. EFFECT OF COLD WORK ON DUCTILITY AT
ROOM TEMPERATURE (Co-20Cr-15W-10Ni)

Reference 14.

Cold Reduction, %	Reduction of Area, %
Fully annealed	55
10	43
15	33
20	27
50	2

TABLE 20. ROOM-TEMPERATURE HARDNESS OF COLD-WORKED AND AGED SHEET (Co-20Cr-15W-10Ni)

Reference 3.

Form(a)	Cold Reduction, %	Aging		Room- Temperature Hardness, Rockwell C
		Temperature, F	Time, hr	
0.050 in. thick	None	--	--	24
	10	--	--	33
	15	--	--	37
	20	--	--	41
0.070 in. thick	None	--	--	24
	None	900	5	25
	None	1100	5	24.5
	None	1100	16	24.5
	5	--	--	31
	5	900	5	33
	5	1100	5	30.5
	5	1100	16	30.5
	10	--	--	37
	10	900	5	39
	10	1100	5	38.5
	10	1100	16	40.5
	15	--	--	39.5
	15	900	5	44
	15	1100	5	42.5
	15	1100	16	44
	20	--	--	43.5
	20	900	5	43.5
	20	1100	5	46.5
	20	1100	16	46.5
	50	--	--	51
	50	900	5	58.5
	50	1100	5	57
	50	1100	16	56.5

(a) Solution heat treated before cold reduction and aging. Data are results of a limited number of tests.

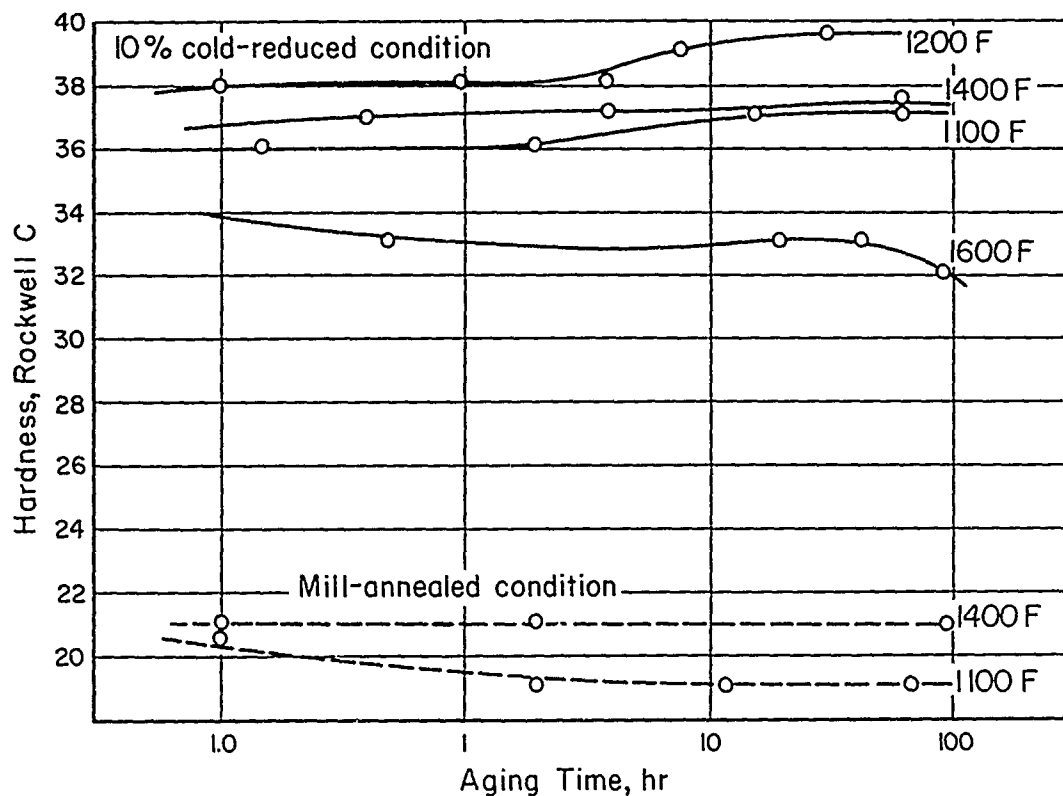


FIGURE 7. EFFECT OF AGING TEMPERATURE AND TIME ON ROOM-TEMPERATURE HARDNESS (Co-20Cr-15W-10Ni)

Reference 15.

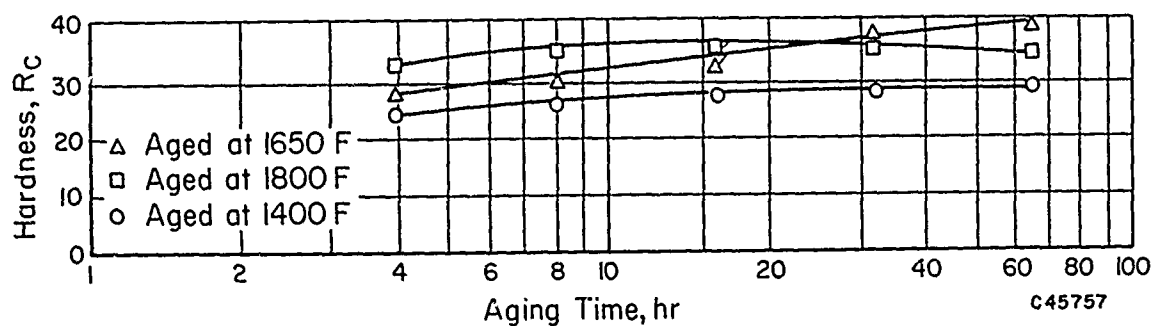


FIGURE 8. EFFECT OF AGING ON ROOM-TEMPERATURE HARDNESS OF 0.109- OR 0.125-IN. SHEET (Co-20Cr-15W-10Ni)

Average of two tests - see Table 17.

Reference 12.

TABLE 21. EFFECT OF COLD ROLLING AND SUBSEQUENT HEAT TREATMENT ON THE HARDNESS OF SHEET (Co-20Cr-15W-10Ni)

Reference 16.

Heat Treatment	Hardness After Indicated Cold Reduction and Heat Treatments, Rockwell C					
	As Rolled	5%	10%	15%	20%	50%
None	24	31	37	39.5	41.5	51
900 F, 5 hr, air cool	25	33	39	44	43.5	58.5
1100 F, 5 hr, air cool	24.5	30.5	38.5	42.5	46.5	58
1100 F, 16 hr, air cool	24.5	30.5	40.5	44	46.5	56.5

TABLE 22. EFFECT OF AGING TREATMENTS ON THE HARDNESS OF COLD-ROLLED 0.062-IN. SHEET (Co-20Cr-15W-10Ni)

Reference 9 - Section A. 1.

Aging Treatment	Rockwell C Hardness for Indicated Cold Reductions			
	As Rolled	15%	20%	25%
As received	15-18	34-37	38-40	41-42
10 hr at 1000 F	13.5	36.6	42.3	44.3
20 hr at 1000 F	14.5	35.6	42.2	44.3
10 hr at 1100 F	15	37.2	42.3	44.8
20 hr at 1100 F	15	36.6	42.0	44.9
40 hr at 1100 F	14.2	36.3	40.3	44.7
20 hr at 1200 F	15.7	35.8	40.0	42.7
40 hr at 1200 F	16.0	35.7	40.0	42.7
10 hr at 1300 F	16.2	35.1	41.5	43.2
20 hr at 1300 F	15.8	37.3	40.4	43.8
10 hr at 1400 F	15.9	37.3	40.2	42.6
20 hr at 1400 F	14.2	39.7	39.7	43.3

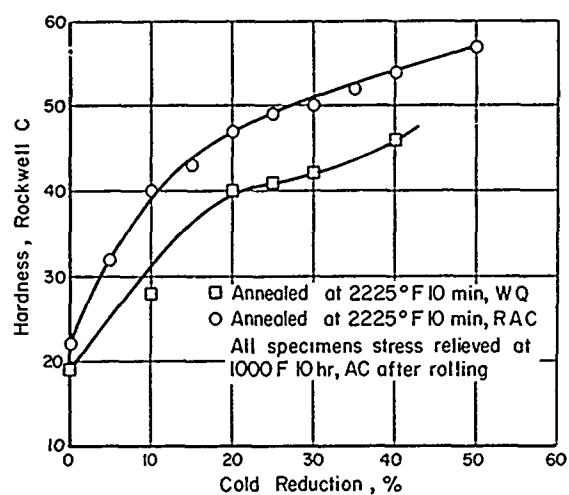


FIGURE 9. EFFECT OF COLD ROLLING AND SUBSEQUENT HEAT TREATMENT ON HARDNESS OF ANNEALED SHEET (Co-20Cr-15W-10Ni)

Reference 16.

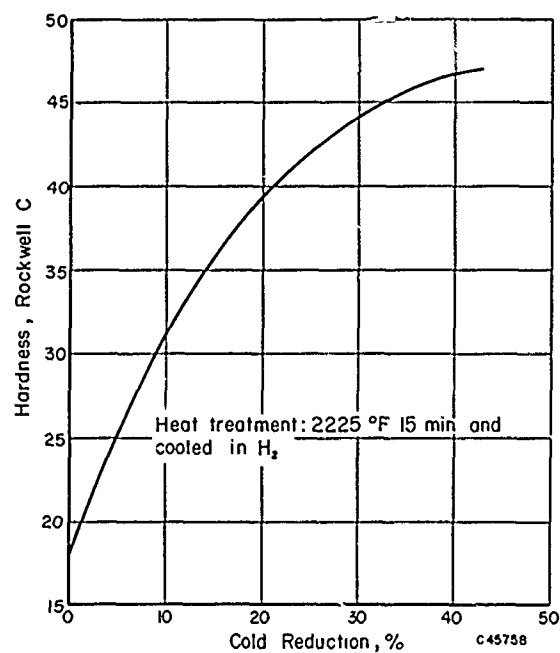


FIGURE 10. EFFECT OF COLD DRAWING AND SUBSEQUENT HEAT TREATMENT ON HARDNESS OF ANNEALED SHEET (Co-20Cr-15W-10Ni)

Reference 16.

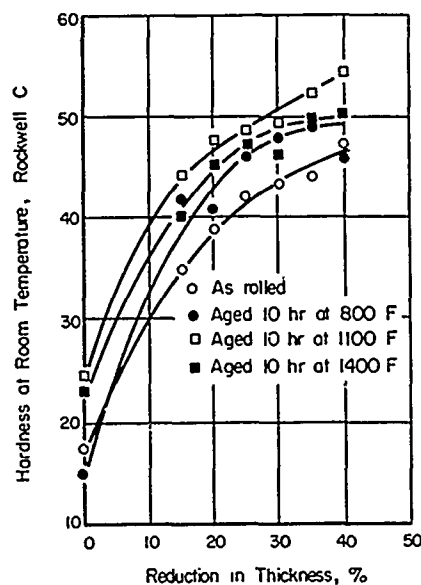


FIGURE 11. THE EFFECT OF COLD ROLLING AND AGING ON ROOM-TEMPERATURE HARDNESS (Co-20Cr-15W-10Ni)

Reference 17.

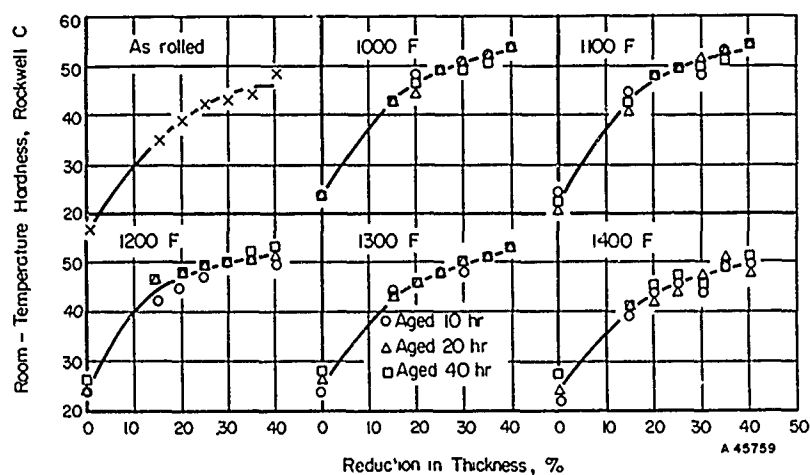


FIGURE 12. EFFECT OF COLD ROLLING AND AGING CONDITIONS ON ROOM-TEMPERATURE HARDNESS (Co-20Cr-15W-10Ni)

Reference 17.

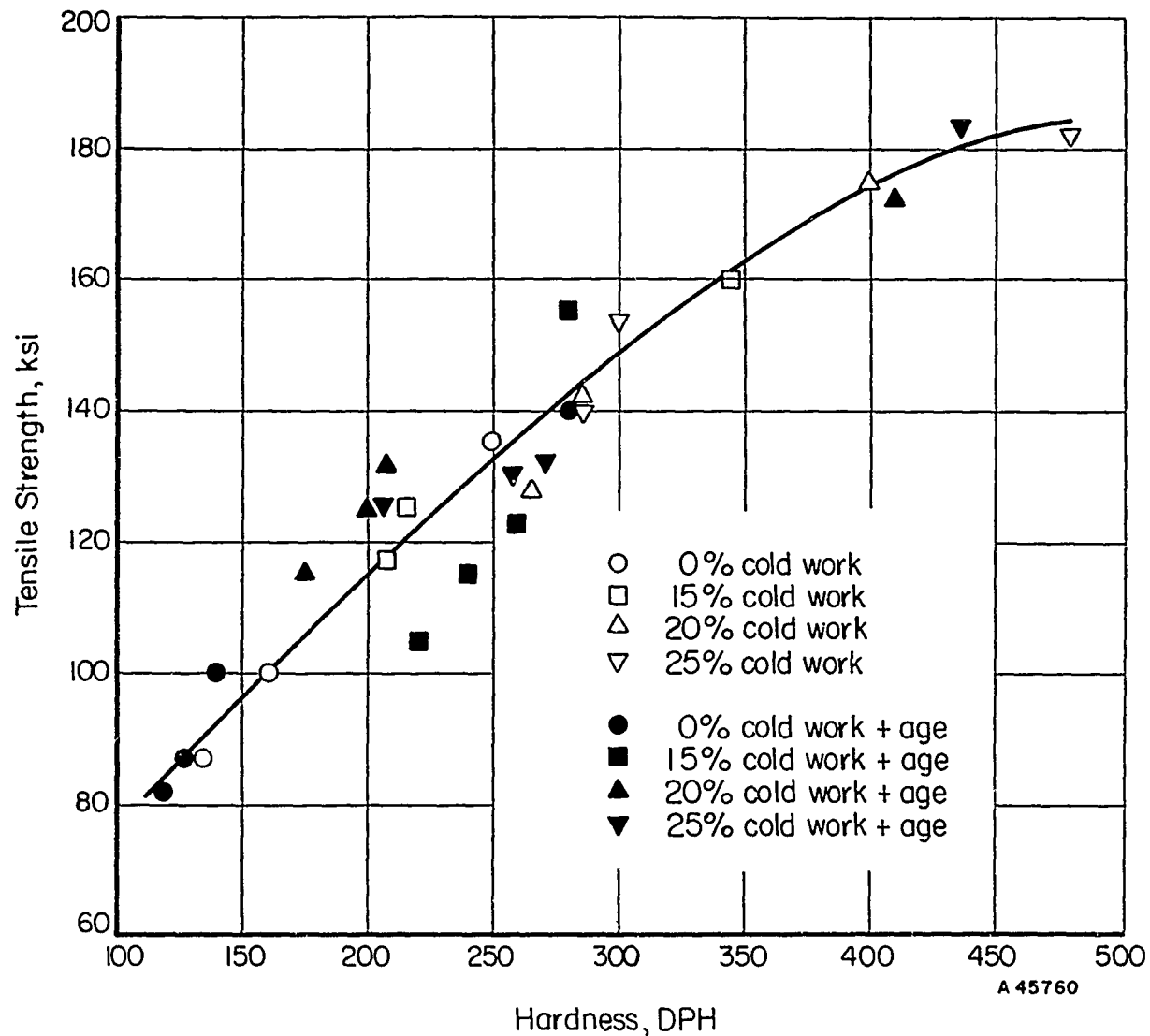


FIGURE 13. TENSILE STRENGTH VERSUS HARDNESS FOR COLD-WORKED AND AGED 0.062-IN. SHEET (Co-20Cr-15W-10Ni)

Aging at 1300 F for 10 hr, air cooled.

Reference 9 - Section A-1.

TABLE 23. ROOM-TEMPERATURE TENSILE PROPERTIES OF 1-IN. -DIAM BAR (Co-20Cr-15W-10Ni)(a)

Reference 7.

Heat	Direction(b)	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength(c), ksi	Modulus, 10 ⁶ psi	Elongation in 2 In., %
E	L	143.2	71.6	33.7	58.3
F	L	140.5	71.0	33.8	58.0
G	L	136.0	65.4	33.5	58.2

(a) Results are averages of five tests for each condition.

(b) L - longitudinal.

(c) Strain rate of 0.005 in./in./min to the yield point, then crosshead speed of 0.06 in./min.

TABLE 24. ROOM-TEMPERATURE HARDNESS OF BAR STOCK (Co-20Cr-15W-10Ni)

Reference 3.

Form	Cold Reduction, %	Aging		Room-Temperature Hardness, Rockwell C
		Temperature, F	Time, hr	
As solution heat treated	None	--	--	24
1-in. diam	11	--	--	38
1 1/16-in. diam	17	--	--	39
1/4-in. diam	26	--	--	45
		950	5	52
1/2-in. diam	34	--	--	46
9/16-in. diam	38	--	--	48
		1100	4	57

TABLE 25. TYPICAL MECHANICAL PROPERTIES OF
WIRE (Co-20Cr-15W-10Ni)

Fifteen per cent cold-reduced wire, heat
treated as indicated.

Reference 18.

Condition	Tensile Strength, ksi	Proportional Limit, ksi	Elongation in 10 In. , %
As drawn	178.5	38.0	24
900 F, 1 hr	186.2	92.3	22
1100 F, 1 hr	187.0	94.5	16
1200 F, 1 hr	182.5	107.5	--
1300 F, 1 hr	181.0	93.0	7
1400 F, 1 hr	175.0	89.5	9
900 F, 16 hr	191.0	99.5	5.5
1000 F, 16 hr	191.2	89.5	4.5
1100 F, 16 hr	177.0	78.5	--
1200 F, 16 hr	182.0	89.5	4.0
1300 F, 16 hr	176.5	78.0	5.0
1400 F, 16 hr	173.0	96.0	9.5
1500 F, 16 hr	167.0	73.5	8.0

TABLE 26. TYPICAL MECHANICAL PROPERTIES OF
WIRE (Co-20Cr-15W-10Ni)

Thirty per cent cold reduced, heat treated
as indicated.

Reference 18.

Condition	Tensile Strength, ksi	Proportional Limit, ksi	Elongation in 10 In. , %
As drawn	207.0	39.8	7.0
900 F, 1 hr	234.0	90.5	1.2
1100 F, 1 hr	237.5	117.0	--
1200 F, 1 hr	198.5	113.3	--
1300 F, 1 hr	195.5	99.0	--
1400 F, 1 hr	197.0	107.5	11.0
900 F, 16 hr	223.0	134.2	--
1100 F, 16 hr	214.0	109.0	--
1200 F, 16 hr	190.5	97.5	--
1300 F, 16 hr	205.0	94.5	9.5
1400 F, 16 hr	196.2	95.0	--
1500 F, 16 hr	189.3	79.5	2.0

TABLE 27. TENSILE STRENGTH VERSUS DIAM OF WIRE
(Co-20Cr-15W-10Ni)

Thirty per cent reduction from the last anneal.

Reference 18.

Wire Diam, in.	Tensile Strength, ksi
0.050	230.5-233.5
0.060	229.0-232.0
0.070	228.0-230.0
0.080	227.0-228.5
0.090	226.0-227.5
0.100	224.5-227.0
0.110	223.0-227.0
0.120	222.0-226.8
0.130	221.0-226.3

TABLE 28. EFFECT OF REDUCTION ON THE TENSILE PROPERTIES
OF WIRE (Co-20Cr-15W-10Ni)

0.125-in. -diam wire.

Reference 18.

Reduction, %	Tensile Strength, ksi	Elongation in 2 In., %
20	190.0	17.0
25	202.0	13.0
30	222.0	5.0
35	236.0	2.5
40	247.5	0.5

TABLE 29. HARDNESS OF WIRE (Co-20Cr-15W-10Ni)

0.242-in. -diam wire, bright annealed
before cold reduction.

Reference 3.

Cold Reduction, %	Room-Temperature Hardness, Rockwell
None	B-97
5	C-20
10	C-29
15	C-36
20	C-39
25	C-41
30	C-44
35	C-45
40	C-47

TABLE 30. RELAXATION DATA AT 600 F (Co-20Cr-15W-10Ni)

Wire, 30 per cent cold reduced, heated 16 hr
at 900 F.

Reference 18.

Stress, psi	Relaxation, % load loss, for Indicated Time					
	5 Hr	10 Hr	20 Hr	50 Hr	100 Hr	140 Hr
20,000	3.0	2.5	--	2.0	2.5	2.5
40,000	0.5	0.5	0.5	0.25	0.25	0.25
60,000	1.1	1.0	1.0	1.2	1.3	1.3
80,000	2.2	2.2	2.2	2.2	2.2	2.2
100,000	1.1	1.2	1.3	1.3	1.3	1.3
118,000	4.0	4.1	4.3	4.9	5.0	5.0

TABLE 31. SHORT-TIME TENSILE PROPERTIES OF 1-MIL WIRE
(Co-20Cr-15W-10Ni)

Wire heated in furnace, reaching temperature in 20 sec and held at temperature 40 sec before testing. Cross-head speed 2 in. per min, corresponding to 1.6 in. /in. /min on estimated 1.25-in. heated portion.

Reference 19.

Test Temperature, F	Ultimate Tensile Strength, ksi	Elongation(a), %
Room	267	1.4
1500	138	10.1
1800	21	34.3
2000	15	23.5
2200	20	2.4

(a) Per cent in 6 in. at room temperature and in 1.25 in. at elevated temperature.

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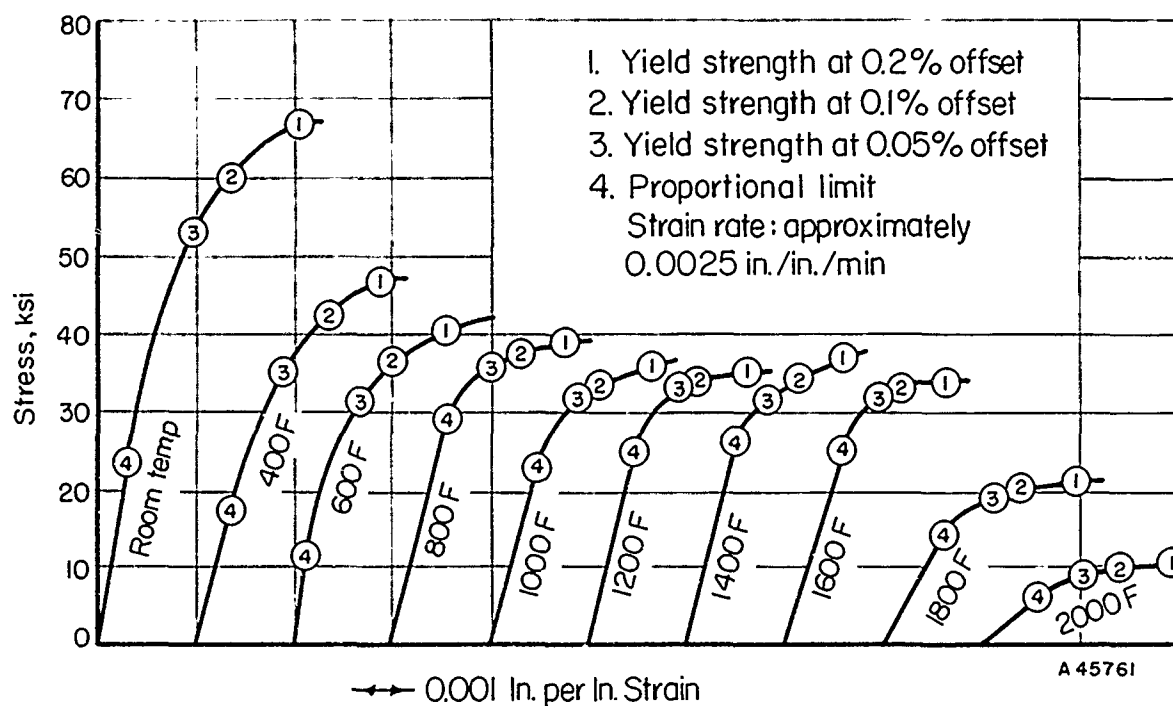


FIGURE 14. TYPICAL STRESS-STRAIN CURVES FOR SHEET (Co-20Cr-15W-10Ni)
 Reference 20.

TABLE 32. TYPICAL SHORT-TIME ELEVATED-TEMPERATURE TENSILE DATA
 (Co-20Cr-15W-10Ni)

0.040-in. sheet, heat treated at 2225 F, rapid air cooled.

Reference 3.

Test Temperature, F	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation in 2 In. , %
Room	146.0	67.0	64.0
600	118.0	--	77.5
800	112.0	--	72.0
1000	100.0	--	68.0
1100	97.0	--	53.5
1200	74.5	--	25.0
1350	54.0	--	13.0
1500	50.0	--	15.0
1650	33.0	--	16.0
1800	22.7	--	16.0
2000	14.0	--	23.3
2100	9.0	--	24.0
2200	7.2	--	22.6
2300	5.1	--	18.6

TABLE 33. TYPICAL ELEVATED-TEMPERATURE TENSILE PROPERTIES OF SHEET (Co-20Cr-15W-10Ni)

Reference 21.

Test Temperature, F	Ultimate Tensile Strength, ksi	Yield Strength, ksi	Elongation in 2 In. , %	Modulus of Elasticity, 10 ⁶ psi	Modulus of Rigidity, 10 ⁶ psi
75	155	70	55	--	12.6
200	142	--	62	--	12.3
300	134	--	67	--	--
400	127	--	71	31.4	11.8
500	122	--	75	--	--
600	118	--	77	30.0	11.2
700	114	--	75	--	--
800	112	--	72	28.6	10.7
900	108	--	71	--	--
1000	102	35	68	27.3	10.2
1200	76	35	25	25.9	9.7
1400	53	37	13	24.6	9.1
1600	40	34	14	23.2	8.6
1800	23	--	18	--	--
2000	13	--	23	--	--

TABLE 34. TYPICAL SHORT-TIME TENSILE DATA (Co-20Cr-15W-10Ni)

0.109-in. sheet, heat treated at 2250 F, rapid air cooled.

Reference 3.

Test Temperature, F	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Proportional Limit, ksi	Elongation in 2 In. , %	Elastic Modulus, 10 ⁶ psi
Room	145.9	67.2	24.1	64	34.2
400	127.6	47.1	17.9	70	27.5
600	127.5	40.4	11.7	72	31.4
800	124.2	39.0	29.1	74	25.3
1000	115.7	35.8	23.4	59	26.8
1200	103.0	35.4	25.5	35	27.4
1400	66.0	37.7	26.7	12	26.3
1600	46.6	34.5	25.7	30	24.9
1800	34.4	23.1	14.8	41	11.8
2000	19.6	12.0	7.7	34	6.1
2100	10.5	8.8	--	21	--
2200	6.8	5.6	--	14	--
2300	4.6	--	--	13	--
2400	3.0	--	--	6	--

TABLE 35. TYPICAL SHORT-TIME ELEVATED-TEMPERATURE TENSILE DATA
(Co-20Cr-15W-10Ni)

0.109-in. sheet, heat treated 1 hr at 2200 F, air cooled.

Reference 22.

Temperature, F	Proportional Limit, ksi	Yield Strength, ksi			Ultimate Strength, ksi	Modulus of Elasticity, 10 ⁶ psi	Elongation, %
		0.05% Offset	0.10% Offset	0.2% Offset			
400	17.7	35.0	42.0	47.2	127.7	29.5	74
	18.1	36.7	42.6	47.1	127.4	25.5	50
600	11.6	34.6	39.2	41.1	102.3	33.1	27(a)
	11.9	27.4	34.1	39.8	126.4	29.8	72
800	29.1	35.6	37.1	38.5	104.3	26.4	31(a)
	29.1	36.7	38.5	39.5	91.2	24.2	26(a)
1000	23.9	32.0	34.6	37.6	82.2	28.3	24(a)
	22.9	29.6	31.7	33.9	96.5	25.3	36(a)
1200	25.9	34.3	35.0	35.9	91.7	29.0	26(a)
	25.0	33.7	34.6	34.6	92.5	25.9	26(a)
1400	26.1	33.0	34.8	36.8	63.9	25.5	12
	27.3	33.6	35.2	37.0	68.1	27.1	12
1600	26.1	32.2	32.8	33.5	47.2	25.3	55
	25.2	32.6	33.9	34.7	47.5	24.5	50

(a) Failed through pinhole.

TABLE 36. TYPICAL SHORT-TIME ELEVATED-TEMPERATURE TENSILE
PROPERTIES (Co-20Cr-15W-10Ni)

Test specimens taken from 0.062-in. sheet.

Reference 23.

Test Temperature, F	0.2% Offset Yield Strength, ksi	Ultimate Strength, ksi	Elongation, %
70	85.8	160.7	47.0
1000	53.9	130.6	40.0
1200	54.9	94.0	29.0
1400	49.0	73.0	12.0
1500	44.9	55.3	16.0
1600	37.0	40.0	25.0
1800	27.5	29.2	37.0

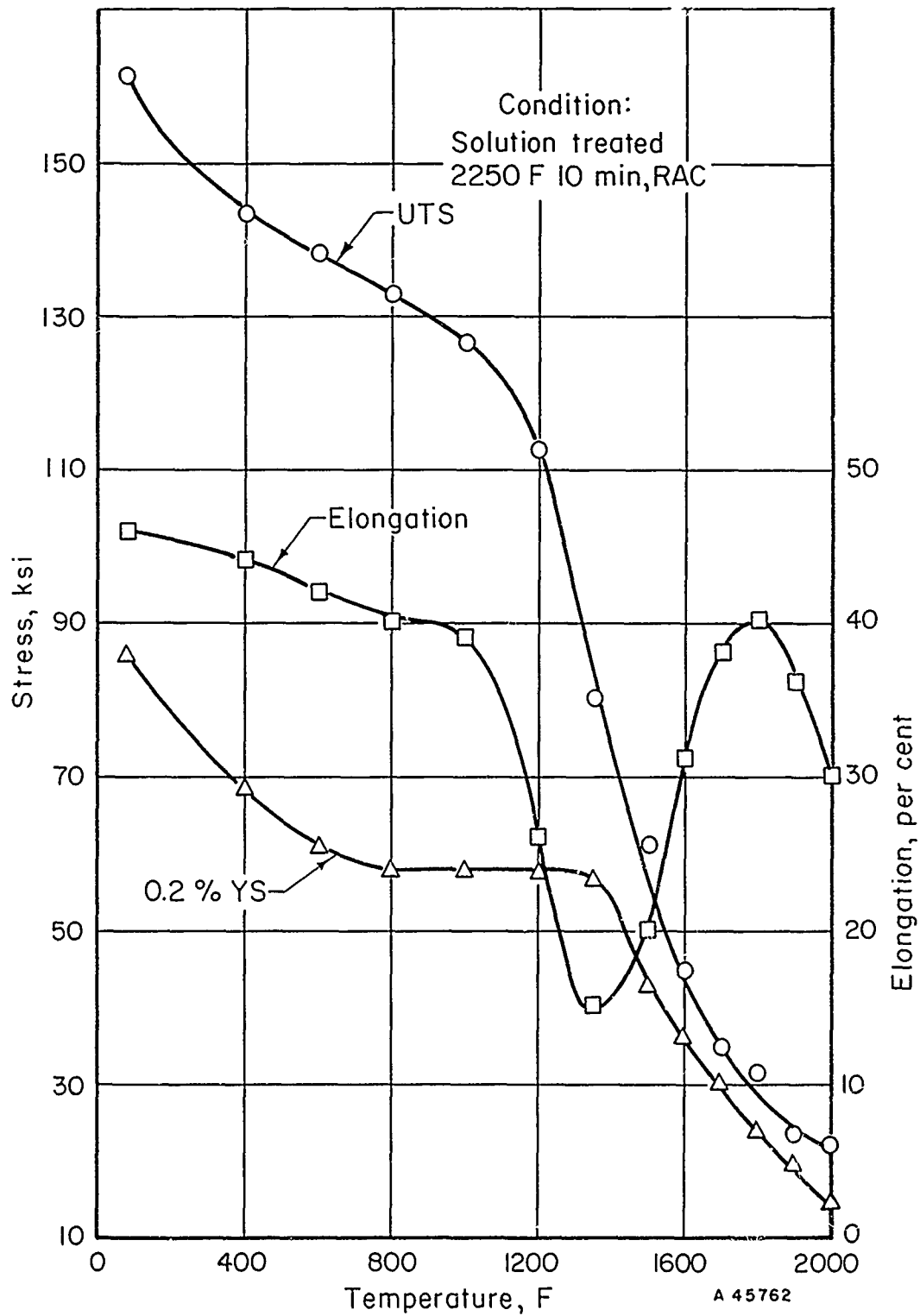


FIGURE 15. SHORT-TIME ELEVATED-TEMPERATURE TENSILE PROPERTIES OF 0.062-IN. SHEET (Co-20Cr-15W-10Ni)

Reference 16.

TABLE 37. MINIMUM EXPECTED SHORT-TIME TENSILE PROPERTIES OF SHEET AT ELEVATED TEMPERATURE (Co-20Cr-15W-10Ni)

Reference 24.

Temperature, F	Minimum Ultimate Tensile Strength, ksi	Minimum 0.2% Yield Strength, ksi
1500	48	25
1600	35	23
1700	29	20
1800	20	16
1900	15	6
2000	10	--

TABLE 38. SHORT-TIME TENSILE TEST RESULTS AT ROOM AND ELEVATED TEMPERATURES ON 0.062-IN. -SHEET MATERIAL (Co-20Cr-15W-10Ni)

Reference 25.

Temperature, F	Ultimate Tensile Strength, ksi	Yield Strength, ksi		Elongation, %
		0.2% Offset	0.02% Offset	
RT	136.0	66.7	55.0	41.0
RT	145.5	71.0	62.7	45.0
1000	110.0	35.6	30.7	59.0
1000	103.5	36.1	31.3	45.0
1200	94.4	33.4	29.0	40.0
1200	100.5	34.6	30.9	43.5
1350	75.4	30.1	25.4	23.0
1350	80.6	33.0	29.3	28.0
1500	64.6	31.9	27.4	27.0
1500	64.0	32.9	29.9	27.5
1650	47.5	32.8	29.5	28.0
1650	43.5	32.3	29.5	26.0
1800	24.5	21.9	17.0	35.0
1800	31.7	26.5	21.8	35.0
1900	12.3	7.4	5.2	18.0
1900	14.9	11.4	9.6	16.5
2000	13.0	9.8	7.5	17.0
2000	10.6	6.9	5.1	22.5
2100	8.0	4.6	3.5	13.0
2100	7.9	5.8	4.8	22.0

Heat-Treat Condition: 2225 F/30 min/air cool

Testing Procedure: Standard short-time tensile tests, strain rate 0.005 in./in./min to yield, 0.05 in./in./min yield to fracture

TABLE 39. SHORT-TIME ELEVATED-TEMPERATURE TENSILE PROPERTIES OF ANNEALED SHEET AND BAR STOCK (Co-20Cr-15W-10Ni)

Reference 26.

Temperature, F	0.2% Offset Yield Strength, ksi	Tensile Strength, ksi	Elongation in 2 In., %	Modulus of Elasticity, 10 ⁶ psi
Room	70.0	155.0	55	35.3
Room	85.8	160.7	47	--
Room ^(a)	57.4	147.6	36 ^(b)	33.0
750	55.9	138.0	40	--
1000	53.9	130.6	40	--
1200	39.4	74.5	25	30.2
1200	54.9	94.0	29	--
1200 ^(a)	--	106.4	34 ^(b)	--
1350	51.3	83.8	11	--
1500	35.0	50.0	15	26.8
1500	44.9	55.3	16	--
1500 ^(a)	--	69.2	42 ^(b)	--
1650	31.9	34.2	30	--
1800	21.0	22.7	16	21.5
1800	27.5	29.2	37	--
2100	--	9.0	24	--

(a) Wrought bar stock, heat treated, 2100 F for 1 hr, air cooled, and 1400 F for 8 hr, air cooled.

(b) Elongation in 1 in.

TABLE 40. SHORT-TIME ELEVATED-TEMPERATURE TENSILE PROPERTIES
(Co-20Cr-15W-10Ni)

Material reported to be in optimum heat-treatment condition.

Reference 27.

Test Temperature, F	Tensile Strength, ksi	Yield Strength, ksi	Elongation in 2 In., %
70	155	70	55
1000	100	35	67
1400	53	37	14
1600	37	34	18
1800	23	--	19
1900	18	--	20
2000	14	--	22
2200	6.8	--	15
2400	3	--	5

TABLE 41. 1200 F SHORT-TIME TENSILE PROPERTIES OF TENSILE SPECIMENS ANNEALED AT 2200 F FOR 15 MIN AFTER FINISH MACHINING
(Co-20Cr-15W-10Ni)

Tests performed at 0.005 in./in./min.

Reference 9 - Section A. 4.

Thickness, in.	Ultimate Tensile Strength, ksi	Yield Strength		Elongation, %
		0.2% Offset, ksi	0.02% Offset, ksi	
0.070	74.5	29.8	29.4	38.5
	78.3	30.3	27.6	29.0
0.030	58.3	27.3	22.3	18.5
	56.1	28.6	27.6	16
0.030	70.0	21.7	17.3	29.0
	54.5	20.9	19.4	20.5
Average design values	88.0	34.0	31.0	--

TABLE 42. EFFECT OF AGING CONDITIONS ON SHORT-TIME ELEVATED-TEMPERATURE ULTIMATE TENSILE STRENGTH
(Co-20Cr-15W-10Ni)

Reference 12.

Aging Conditions	Ultimate Tensile Strength, ksi, at Indicated Testing Temperature						
	Room	500 F	700 F	1000 F	1200 F	1400 F	1650 F
1400 F, 8 hr	137.5	124.5	113.0	--	94.8	92.3	48.8
	135.0	112.5	79.7	104.0	109.5	90.0	41.5
1650 F, 8 hr	129.5	116.0	110.5	107.5	103.5	92.8	42.8
	126.0	119.0	118.0	102.5	111.0	81.2	37.9
1800 F, 8 hr	135.0	114.0	125.5	114.5	114.0	84.0	47.2
	127.0	130.0	130.0	110.0	117.0	73.8	48.0
1800 F, 8 hr +	119.5	114.0	115.0	109.5	100.5	88.8	52.5
1400 F, 8 hr	112.5	118.0	109.5	108.5	113.0	86.0	45.8
1800 F, 8 hr +	120.0	122.5	98.0	118.5	120.0	93.0	49.4
1650 F, 8 hr	134.0	--	126.0	112.5	115.5	80.5	40.0
1400 F, 8 hr +	132.5	118.5	121.0	109.0	112.0	87.5	51.8
1650 F, 8 hr	136.5	112.0	123.5	109.5	108.0	77.5	49.7

TABLE 43. ELONGATION AT ROOM AND ELEVATED TEMPERATURE OF AGED SHEET (Co-20Cr-15W-10Ni)

Reference 12.

Aging Conditions	Elongation in 2 In. , %, at Indicated Testing Temperature						
	Room	500 F	700 F	1000 F	1200 F	1400 F	1650 F
1400 F, 8 hr	49	55	53	--	52	27	33
	32	49	38	64	52	27	45
1650 F, 8 hr	17	34	38	38	33	24	42
	17	34	33	38	39	28	34
1800 F, 8 hr	9	16	21	18	21	18	38
	6	22	18	17	24	30	48
1800 F, 8 hr + 1400 F, 8 hr	4	13	17	16	11	28	57
	3	15	13	14	16	32	64
1800 F, 8 hr + 1650 F, 8 hr	3	18	7	18	17	23	56
	6	--	16	15	15	43	55
1400 F, 8 hr + 1650 F, 8 hr	17	33	36	27	30	23	57
	17	38	27	39	35	42	53

TABLE 44. 1200 F SHORT-TIME TENSILE PROPERTIES OF 0.030-IN. SHEET WITH DIFFERENT THERMAL TREATMENTS (Co-20Cr-15W-10Ni)

Reference 9 - Section A-4.

	Ultimate Tensile Strength, ksi	Yield Strength, ksi, at		Elongation, %
		0.2% Offset	0.02% Offset	
Annealed, 2250 F	70.0	21.7	17.3	29.0
	54.5	20.9	19.4	20.5
As received, +1650 F, 1 Hr	88.6	36.8	32.6	22.0
	91.0	38.6	35.4	37.0
Annealed, 2050 F, 1 Hr, +1650 F, 1 Hr	85.0	28.4	26.8	20.0
	86.0	30.3	26.8	25.0

TABLE 45. ROOM-TEMPERATURE AND ELEVATED-TEMPERATURE TENSILE DATA (Co-20Cr-15W-10Ni)

Cold-worked 0.062-in. sheet.

Reference 9 - Section A. 1.

Cold Work, %	Test Temperature, F	Tensile Strength, ksi	Yield Strength		Elongation, %
			0.2% Offset, ksi	0.02% Offset, ksi	
0	RT	137.0	62.0	38.4	56.0
0	RT	135.4	65.6	48.9	55.5
0	RT	133.7	62.9	39.2	54.0
0	1000	100.1	30.0	22.9	68.0
0	1000	99.8	29.4	19.6	61.0
0	1000	100.0	29.9	26.0	74.0
0	1200	91.7	27.9	26.9	51.5
0	1200	92.0	28.8	24.4	52.0
0	1200	91.5	27.4	22.3	53.0
15	RT	160.0	118.1	78.0	30.0
15	RT	160.0	118.6	83.6	28.5
15	RT	160.0	119.8	82.5	28.0
15	1000	126.0	86.5	71.8	45.0
15	1000	128.1	88.0	70.0	35.5
15	1000	127.0	89.0	70.7	35.5
15	1200	117.0	87.5	69.5	18.0
15	1200	117.0	85.6	66.0	19.2
15	1200	119.9	87.0	69.4	20.0
20	RT	173.5	130.2	77.5	21.0
20	RT	175.1	128.2	76.1	17.0
20	RT	174.8	136.0	90.9	18.0
20	1000	139.8	111.0	101.0	25.0
20	1000	139.3	112.8	85.0	23.0
20	1000	142.0	110.2	95.5	34.0
20	1200	126.8	105.0	83.3	12.5
20	1200	125.0	108.1	90.5	8.5
20	1200	127.0	107.0	89.6	7.5
25	RT	182.6	147.9	100.0	13.0
25	RT	181.5	143.0	91.0	13.0
25	RT	182.0	143.0	90.5	13.0
25	1000	151.0	122.0	92.0	12.0
25	1000	152.5	120.0	88.5	16.0
25	1000	154.9	124.0	94.0	20.0
25	1200	139.0	120.2	92.2	3.0
25	1200	140.4	119.8	91.6	6.0
25	1200	141.0	125.9	111.0	4.0

TABLE 46. ROOM-TEMPERATURE AND ELEVATED-TEMPERATURE TENSILE DATA FOR COLD-WORKED AND AGED 0.062-IN. SHEET (Co-20Cr-15W-10Ni)

Age at 1300 F, 10 hr.

Reference 9 - Section A. 1.

Cold Work, %	Test Temperature, F	Tensile Strength, ksi	Yield Strength		Elongation, %
			0.2% Offset, ksi	0.02% Offset, ksi	
0	RT	141.8	67.3	60.4	61.0
0	RT	139.0	66.2	59.8	59.5
0	RT	137.2	65.7	59.0	59.0
0	1000	103.0	31.9	30.2	67.5
0	1000	101.0	32.6	31.0	68.5
0	1200	89.0	30.8	27.9	40.0
0	1200	93.5	30.6	27.9	48.5
0	1350	80.4	29.0	25.8	27.5
0	1350	75.3	28.9	26.0	24.0
15	RT	164.0	125.0	107.8	25.0
15	RT	163.0	124.0	109.2	24.0
15	RT	162.0	123.0	107.7	23.5
15	1000	123.1	84.0	73.3	25.0
15	1000	124.0	83.4	70.0	29.0
15	1200	116.5	83.3	70.5	19.5
15	1200	120.8	82.3	76.5	20.0
15	1350	103.0	77.8	72.0	10.0
15	1350	104.1	76.6	71.5	10.0
20	RT	171.9	147.0	120.6	12.0
20	RT	173.0	148.1	121.0	12.0
20	RT	172.5	149.0	128.2	12.0
20	1000	133.0	104.2	90.3	16.0
20	1000	133.1	106.0	89.0	15.0
20	1200	131.0	104.0	85.0	11.5
20	1200	132.5	103.5	85.0	14.5
20	1350	114.2	93.0	69.0	8.0
20	1350	110.2	92.3	70.4	7.0
25	RT	183.0	164.2	137.0	6.5
25	RT	182.0	163.0	136.0	6.5
25	RT	182.0	162.0	136.0	4.5
25	1000	144.0	121.0	105.0	10.0
25	1000	143.0	118.1	99.5	9.0
25	1200	141.9	118.1	93.0	7.5
25	1200	140.7	118.0	96.0	7.0
25	1350	122.1	--	--	6.0
25	1350	128.0	105.5	81.0	6.0

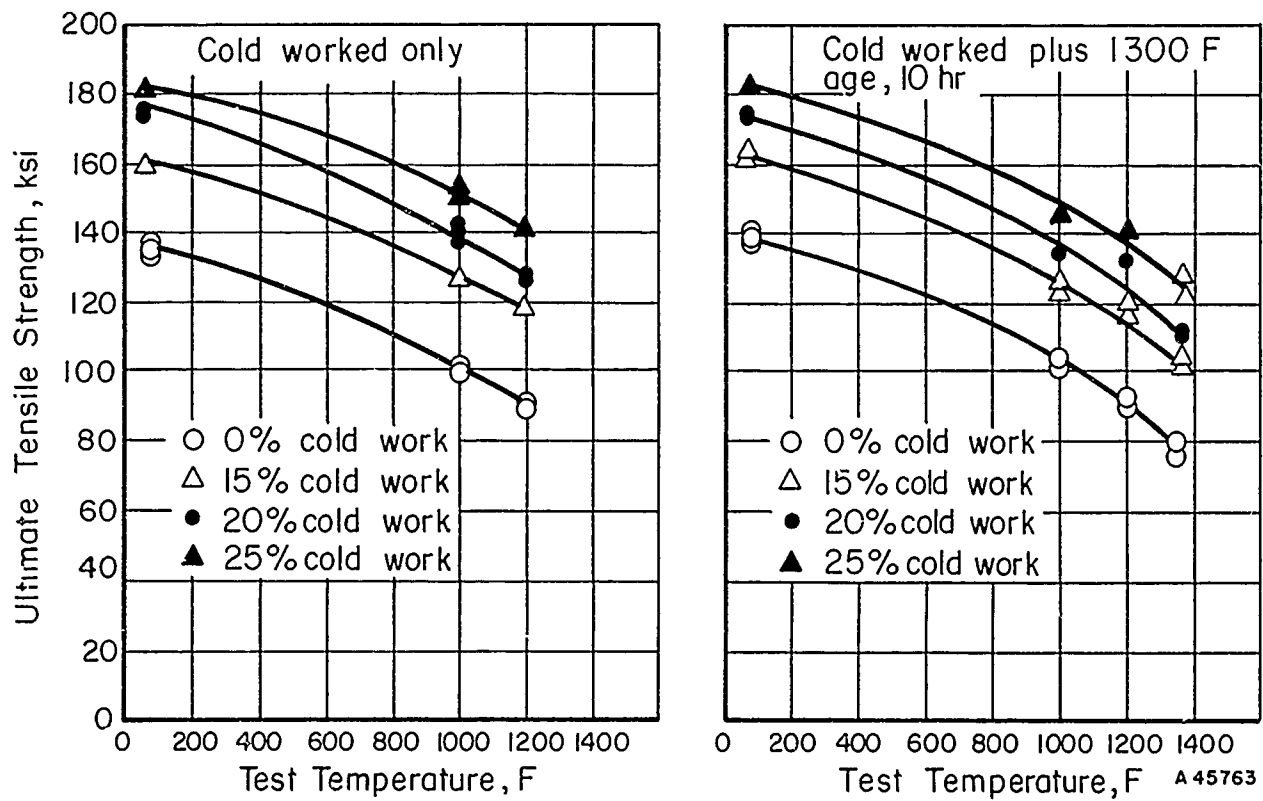


FIGURE 16. EFFECT OF COLD WORK AND AGING ON THE ELEVATED-TEMPERATURE TENSILE STRENGTH OF 0.062-IN. SHEET (Co-20Cr-15W-10Ni)

Reference 9 - Section A-1.

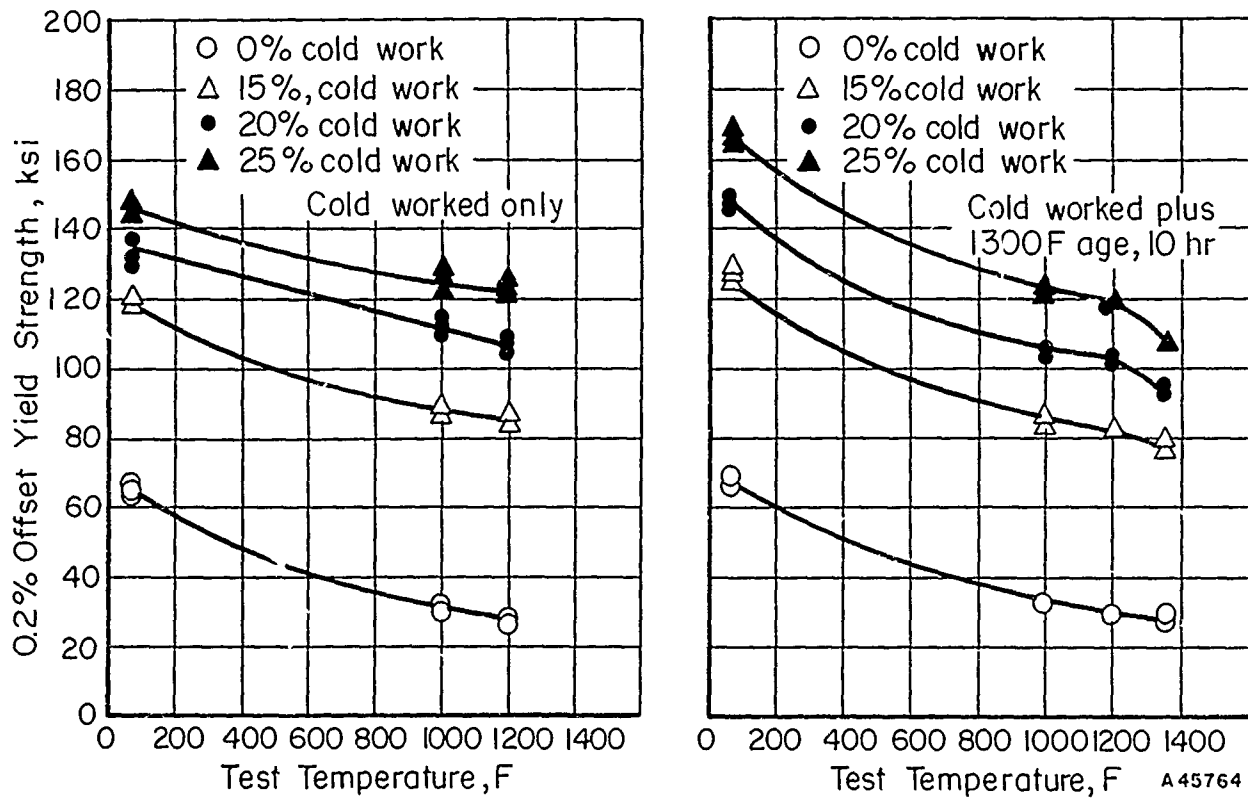


FIGURE 17. EFFECT OF COLD WORK AND AGING ON THE ELEVATED-TEMPERATURE YIELD STRENGTH OF 0.062-IN. SHEET (Co-20Cr-15W-10Ni)

Reference 9 - Section A-1.

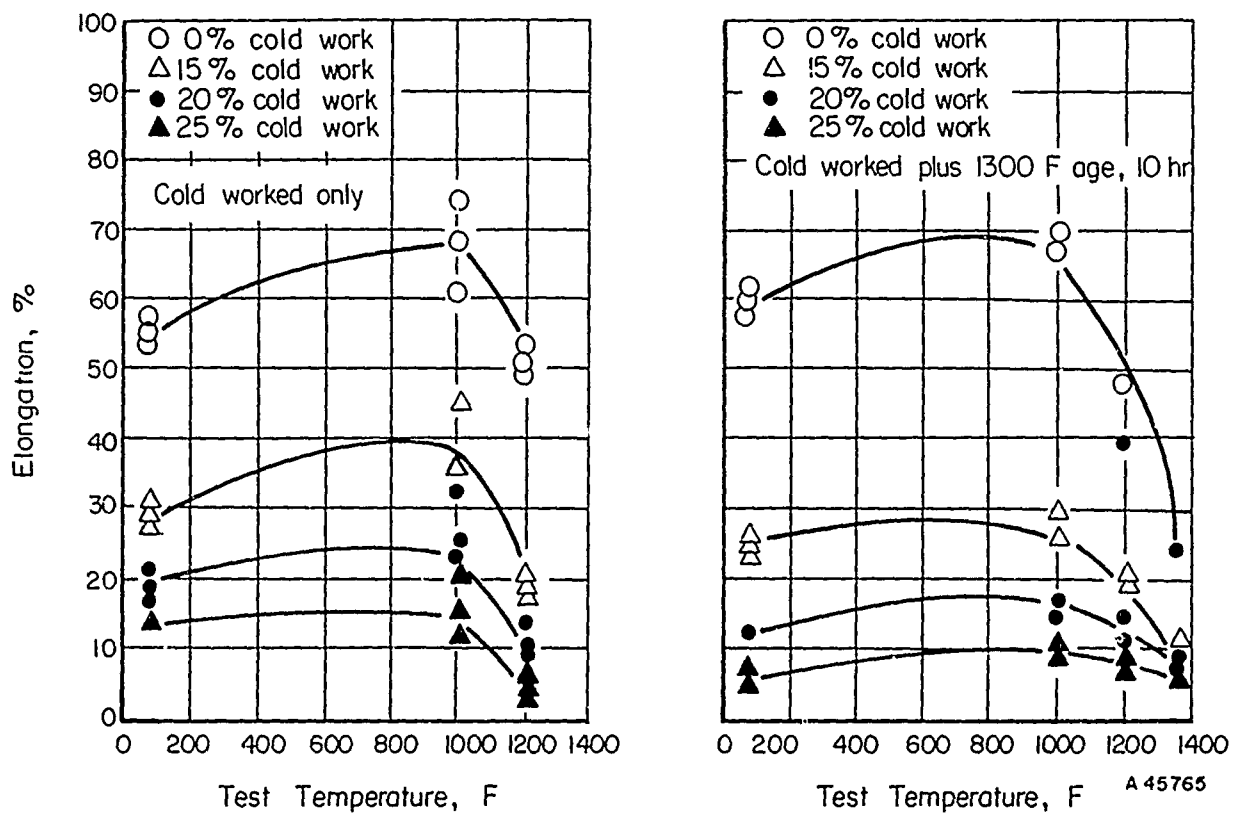


FIGURE 18. EFFECT OF COLD WORK AND AGING ON THE ELONGATION OF 0.062-IN. SHEET (Co-20Cr-15W-10Ni)

Reference 9 - Section A-1.

TABLE 47. TYPICAL SHORT-TIME TENSILE DATA, COLD-REDUCED 0.050-IN. SHEET (Co-20Cr-15W-10Ni)

Sheet solution heat treated at 2250 F and rapid air cooled prior to cold reduction.

Reference 20.

Test Temperature, F	Cold Reduction, %	Aging		Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation in 2 In., %
		Temperature, F	Time, hr			
Room	None(a)	--	--	146.0	67.0	64.0
"	10	--	--	155.0	105.0	41.0
"	15	--	--	166.0	124.0	30.0
"	15	700	1	168.0	136.0	31.0
"	20	--	--	183.0	141.0	19.0
"	20	700	1	181.0	152.0	17.0
"	20	1100	2	191.0	162.0	16.0
600	20	1100	2	164.5	131.8	28.0
1000	None(a)	--	--	115.7	35.8	59.0
"	10	--	--	114.0	78.0	48.0
"	15	--	--	134.0	107.0	29.0
"	20	--	--	156.0	133.0	18.0
"	20	700	1	151.0	129.0	18.5
"	20	1100	2	149.0	124.0	23.0
1200	None(a)	--	--	103.0	35.4	35.0
"	10	--	--	115.0	80.0	37.0
"	15	--	--	129.0	111.0	15.0
"	15	700	1	128.0	104.0	23.0
"	20	--	--	137.0	120.0	2.0
"	20	700	1	144.0	128.0	8.0
"	20	1100	2	140.0	119.0	13.0
1400	None(a)	--	--	66.0	37.7	12.0
"	10	--	--	87.0	67.0	8.0
"	15	--	--	104.0	86.0	5.0
"	20	--	--	107.0	96.0	3.0
"	20	700	1	107.5	96.5	2.0
"	20	1100	2	116.4	92.3	7.0
1600	None(a)	--	--	46.6	34.5	30.0
"	10	--	--	62.0	47.0	13.0
"	15	--	--	70.0	52.0	9.0
"	20	700	1	74.0	59.0	6.0
"	20	1100	2	71.3	50.4	9.0
1800	None(a)	--	--	34.4	23.1	41.0
"	10	--	--	39.0	27.0	15.0
"	15	--	--	40.0	30.0	5.0
"	20	--	--	41.0	29.6	4.0
"	20	700	1	42.5	32.6	5.0
"	20	1100	2	42.2	30.5	12.0

Properties of solution-heat-treated 0.109-in. sheet listed for comparison.

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TABLE 48. EFFECT OF COLD WORK ON ELEVATED-TEMPERATURE TENSILE PROPERTIES (Co-20Cr-15W-10Ni)

Sheet cold reduced 10 per cent, tested in as-rolled condition.

Reference 14.

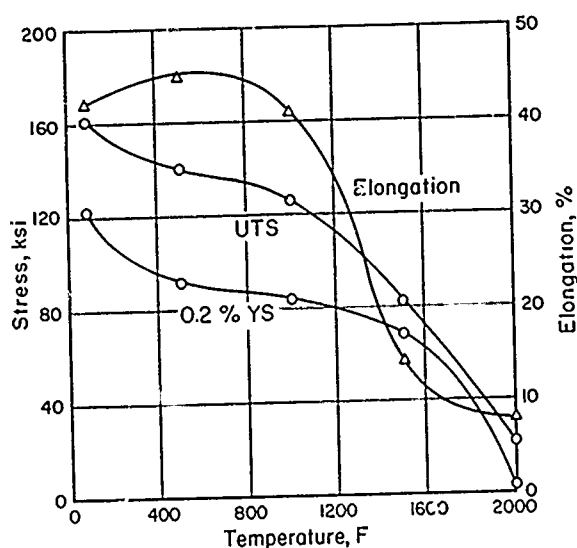
Test Temperature, F	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation, %	Index YS/D
1200	128	87	18.3	262,000
1500	94	67	13	200,500
1800	41	26	16.5	78,700

TABLE 49. EFFECT OF COLD WORKING AND AGING ON TENSILE PROPERTIES AT 1200 F (Co-20Cr-15W-10Ni)

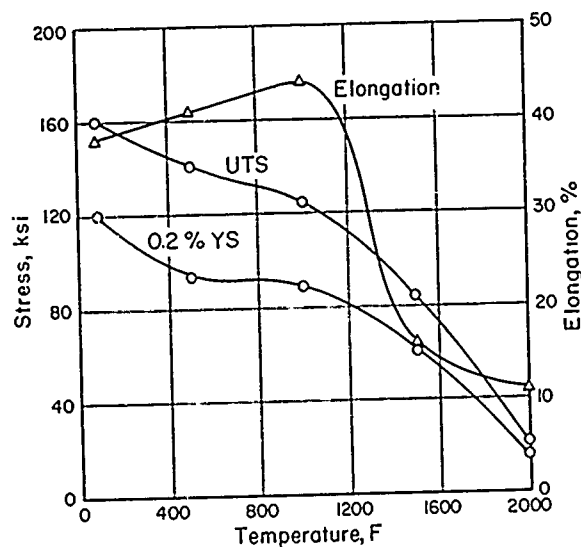
Specimens cold reduced, then aged for 16 hr at 1380 F.

Reference 14.

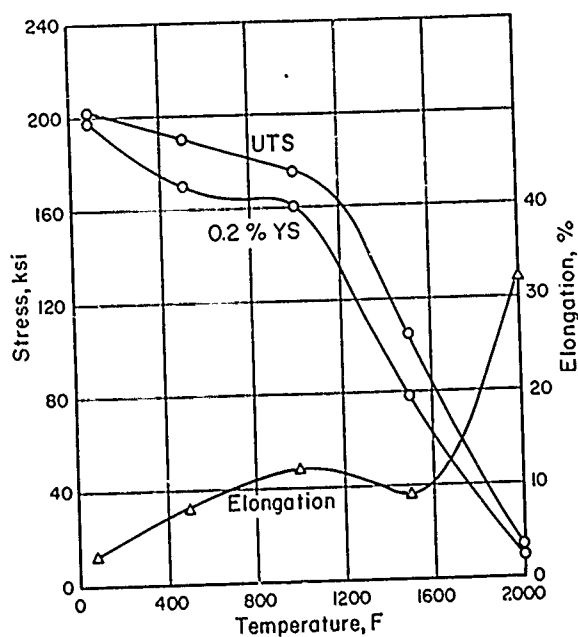
Cold Reduction, %	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation, %	Index, YS/D
35	160	107	8.5	322,100
40	150	106	7.3	319,600
45	147	117	6.3	350,000
Annealed sheet	--	35	--	107,000



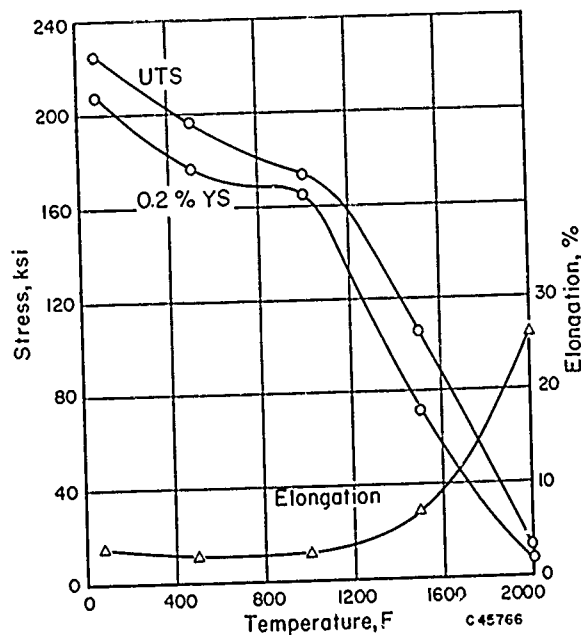
a. Solution Annealed 2200 F 15 Min, RAC; Cold Reduced 10%; Heated 900 F 4 Hr, AC



b. Solution Annealed 2200 F 15 Min, RAC; Cold Reduced 10%; Heated 1200 F 4 Hr, AC



c. Solution Annealed 2250 F 15 Min, RAC; Cold Reduced 20%; Heated 900 F 4 Hr, AC



d. Solution Annealed 2200 F 15 Min, RAC; Cold Reduced 20%; Heated 1200 F 4 Hr, AC

FIGURE 19. EFFECT OF COLD WORK AND SUBSEQUENT HEAT TREATMENT ON THE ELEVATED-TEMPERATURE PROPERTIES OF 0.063-IN. SHEET (Co-20Cr-15W-10Ni)

Reference 16.

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TABLE 50. TENSILE PROPERTIES OF SHEET - STRAIN RATE: 0.00001 IN./IN./SEC
(Co-20Cr-15W-10Ni)

Method of heating = resistance
 Time to temperature = 200 F/sec
 Hold time = 2 min
 Strain rate = 0.00001 in./in./sec to yield strength
 = 0.01 in./in./sec to rupture
 Sheet thickness = 0.063 in.
 Gage length = 2.0 in.
 Heat treatment = solution heat treated

Reference 29.

Test Temperature, F	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Modulus of Elasticity, 10^6 psi
RT	47.0	61.2	122.0	50	29.3
RT	47.0	61.0	132.0	65	30.2
RT	40.2	63.0	134.0	52	30.7
RT	48.0	62.0	123.5	33	30.3
800	26.0	36.0	99.2	50	23.0
800	27.0	36.8	99.9	53	25.0
800	25.0	36.1	100.5	55	23.0
1200	27.0	34.0	85.2	46	22.0
1200	21.0	31.9	83.9	43	18.9
1200	29.0	33.5	84.0	43	22.5
1400	24.5	28.9	83.0	42	20.9
1400	25.5	28.5	78.9	35	19.4
1400	26.0	29.0	83.5	53	20.0
1600	18.0	23.3	59.0	31	17.9
1600	14.0	22.9	58.5	29	16.5
1600	16.0	21.5	59.4	31	17.2
1800	9.0	11.8	36.8	28	14.5
1800	8.0	11.0	38.0	31	13.0
1800	9.2	11.8	36.0	30	14.9
2000	--	4.5	23.5	24	12.2
2000	3.9	5.5	24.6	25	11.5
2000	--	5.0	24.3	25	9.9
2200	--	2.7	13.2	30	5.2
2200	--	2.8	12.2	21	3.8
2200	--	2.8	12.0	30	3.5

TABLE 51. TENSILE PROPERTIES OF SHEET - STRAIN RATE: 0.001 IN./IN./SEC
(Co-20Cr-15W-10Ni)

Method of heating = resistance
 Time to temperature = 200 F/sec
 Strain rate = 0.001 in./in./sec to yield strength
 0.01 in./in./sec to rupture
 Sheet thickness = 0.063 in.
 Gage length = 2.0 in.
 Heat treatment = solution heat treated

Reference 29.

Test Temperature, F	Hold Time, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Modulus of Elasticity, 10 ⁶ psi
RT	--	51.0	69.5	134.3	50	30.0
RT	--	50.0	72.0	129.0	35	29.0
RT	--	40.0	68.9	134.0	53	29.0
800	2	28.0	38.0	105.0	50	26.0
800	2	25.0	36.0	105.2	55	24.0
800	30	25.0	36.0	106.3	66	21.5
800	2	28.5	37.3	106.2	60	23.0
1200	2	27.0	33.0	75.4	30	21.8
1200	2	25.0	34.0	87.0	52	19.2
1200	30	30.0	34.8	85.4	40	20.9
1400	2	25.0	32.5	78.4	33	18.0
1400	2	26.0	31.5	79.4	34	22.0
1400	30	27.8	31.1	83.3	35	22.0
1600	2	25.0	29.8	57.8	29	18.5
1600	2	25.6	28.9	58.9	29	19.6
1600	30	24.9	28.0	59.2	35	20.9
1800	2	21.0	26.8	36.5	25	19.9
1800	2	20.2	26.5	34.4	24	19.0
1800	30	21.0	26.9	37.7	32	18.2
2000	2	12.1	13.4	20.6	22	13.0
2000	2	12.5	14.4	21.7	24	12.8
2000	30	12.5	12.7	20.0	28	12.8
2200	2	5.2	6.4	10.9	28	6.9
2200	2	5.8	7.0	11.9	28	6.8
2200	30	6.4	6.8	11.8	32	7.2

TABLE 52. TENSILE PROPERTIES OF SHEET - STRAIN RATE: 0.1 IN./IN./SEC
(Co-20Cr-15W-10Ni)

Method of heating = resistance
 Time to temperature = 200 F/sec
 Hold time = 2 min
 Strain rate = 0.1 in./in./sec to rupture
 Sheet thickness = 0.063 in.
 Gage length = 2.0 in.
 Heat treatment = solution heat treated

Reference 29.

Test Temperature, F	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Modulus of Elasticity, 10 ⁶ psi
RT	58.0	78.0	138.0	64	31.0
RT	59.0	76.0	131.0	62	30.0
RT	56.0	78.0	125.0	33	31.5
RT	64.0	77.9	132.0	60	30.1
800	34.0	41.5	93.5	42	26.0
800	29.8	39.4	92.0	45	24.3
800	35.9	43.0	86.5	33	27.9
1200	28.0	34.0	81.0	42	20.0
1200	29.0	37.0	78.0	36	18.0
1200	29.3	36.8	73.5	32	19.7
1400	27.0	33.0	82.0	54	18.7
1400	27.7	33.5	79.9	41	19.2
1400	26.0	32.0	78.4	45	18.5
1600	24.0	31.4	71.5	39	16.6
1600	25.0	31.8	71.0	39	15.9
1600	23.8	30.0	68.0	39	16.0
1800	21.0	27.9	47.4	33	14.2
1800	23.0	29.0	45.9	30	15.8
1800	21.8	27.8	44.9	28	15.2
2000	18.0	24.4	31.5	28	9.8
2000	17.9	24.7	30.8	31	10.4
2000	18.5	24.5	30.7	30	9.6
2200	13.0	16.2	17.2	37	5.4
2200	14.0	17.3	18.4	34	5.2
2200	15.2	18.0	18.5	34	5.8

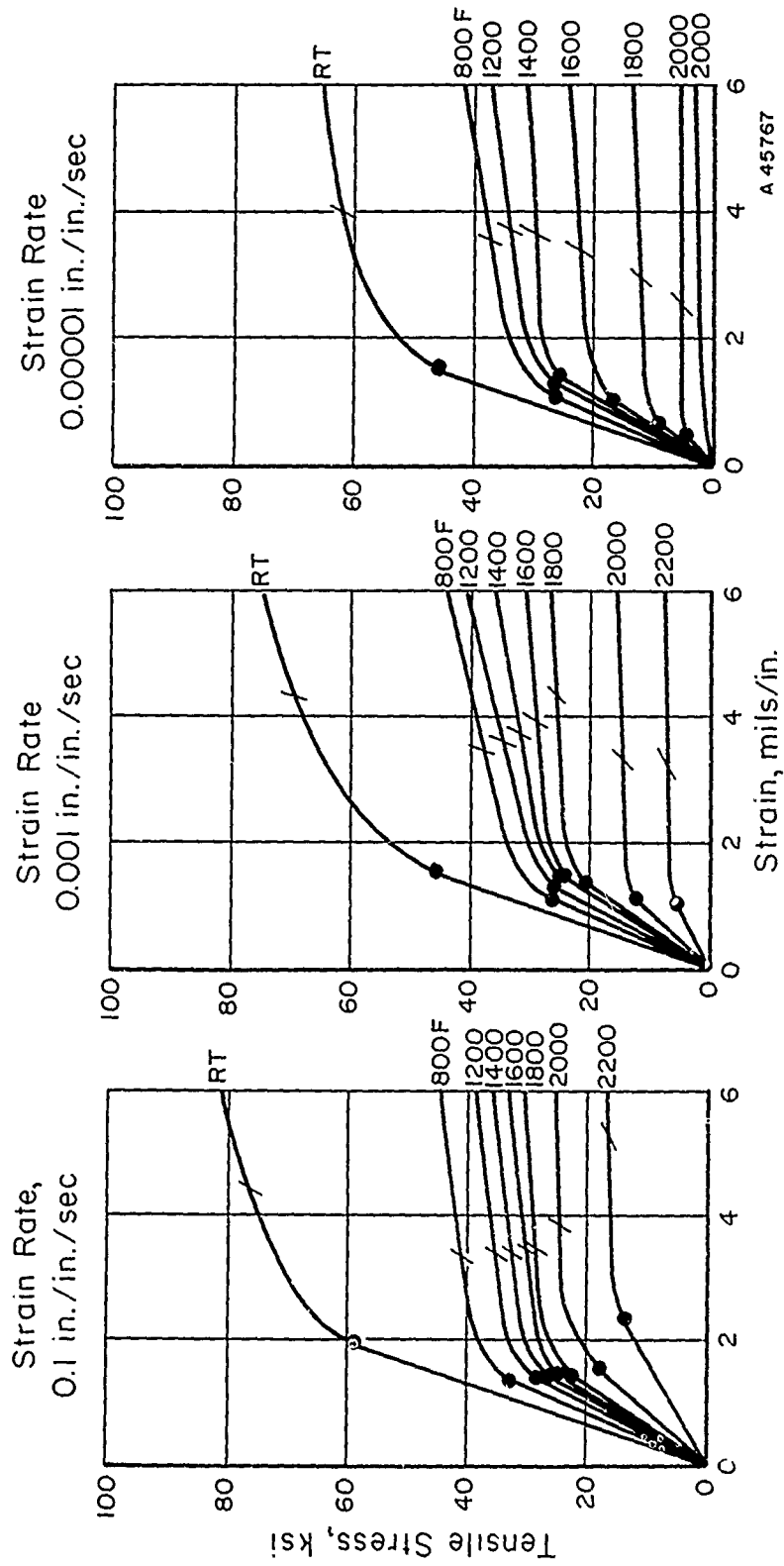


FIGURE 20. TYPICAL TENSILE STRESS-STRAIN CURVES (Co-20Cr-15W-10Ni)

Sheet thickness = 0.063 in.

Heating = resistance

Heat treatment = solution heat treated

Reference 29.

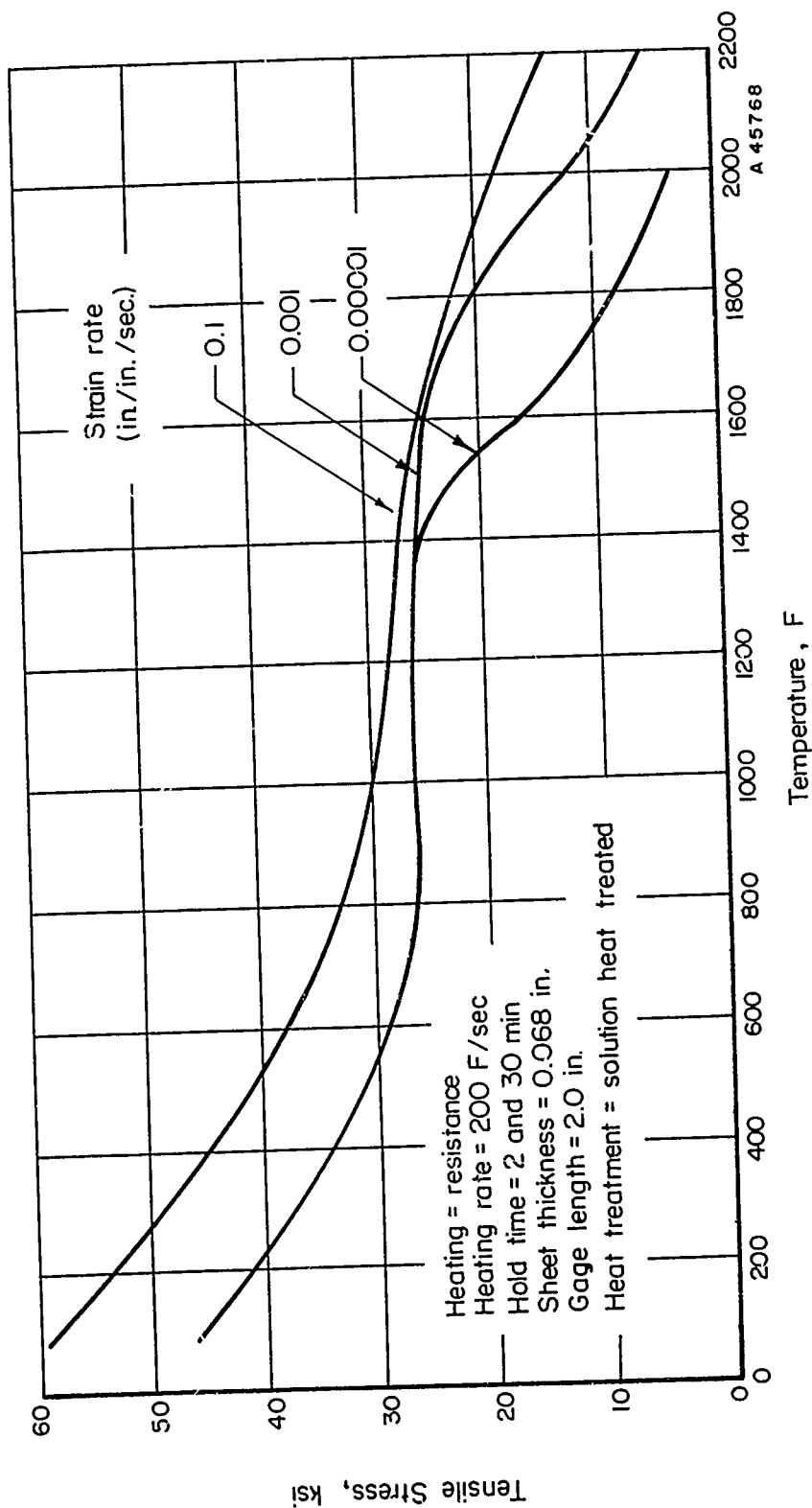


FIGURE 21. TYPICAL TENSILE-PROPORTIONAL-LIMIT CURVES (Co-20Cr-15W-10Ni)

Reference 29.

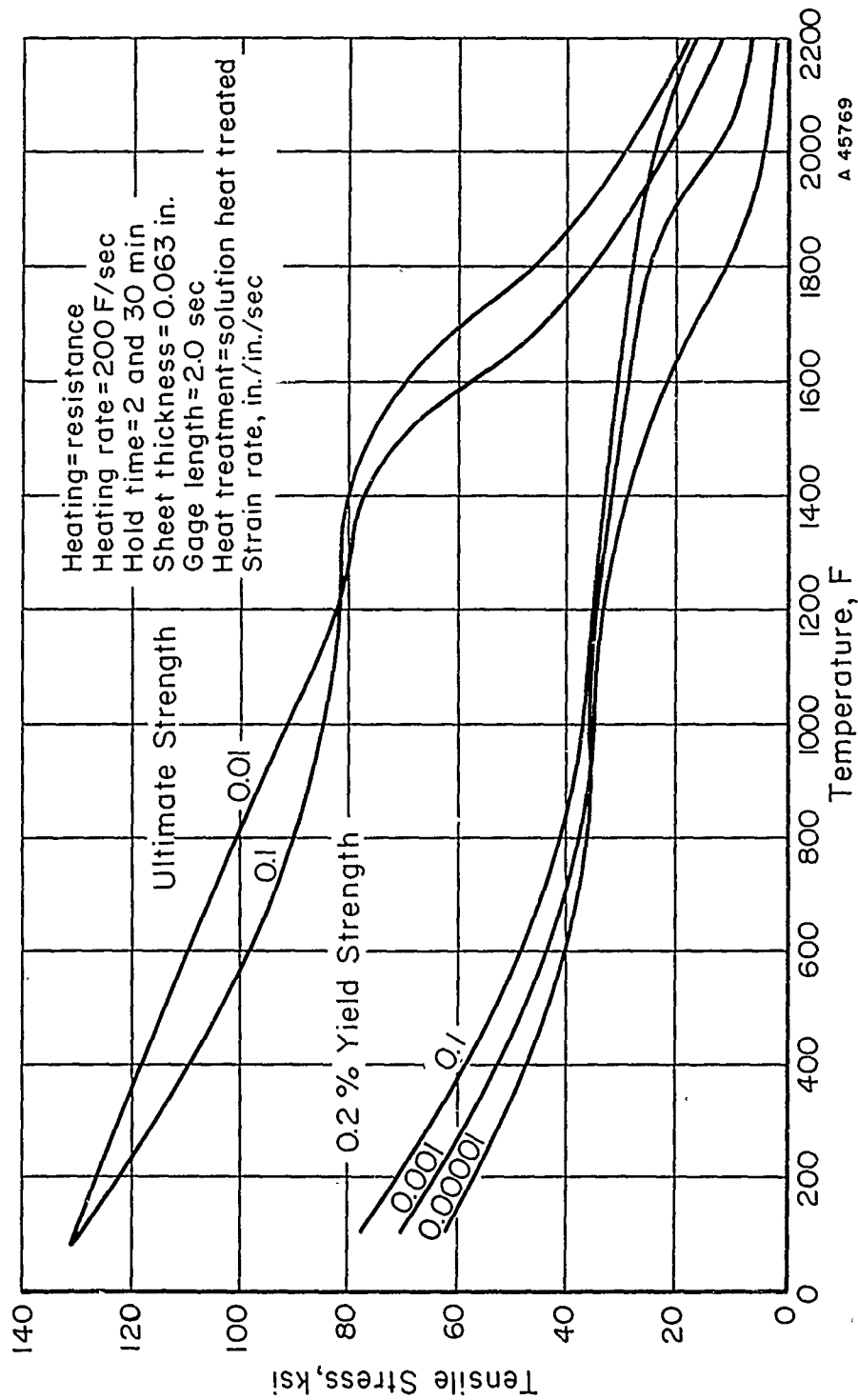


FIGURE 22. TYPICAL TENSILE- AND YIELD-STRENGTH CURVES (Co-20Cr-15W-10Ni)

Reference 29.

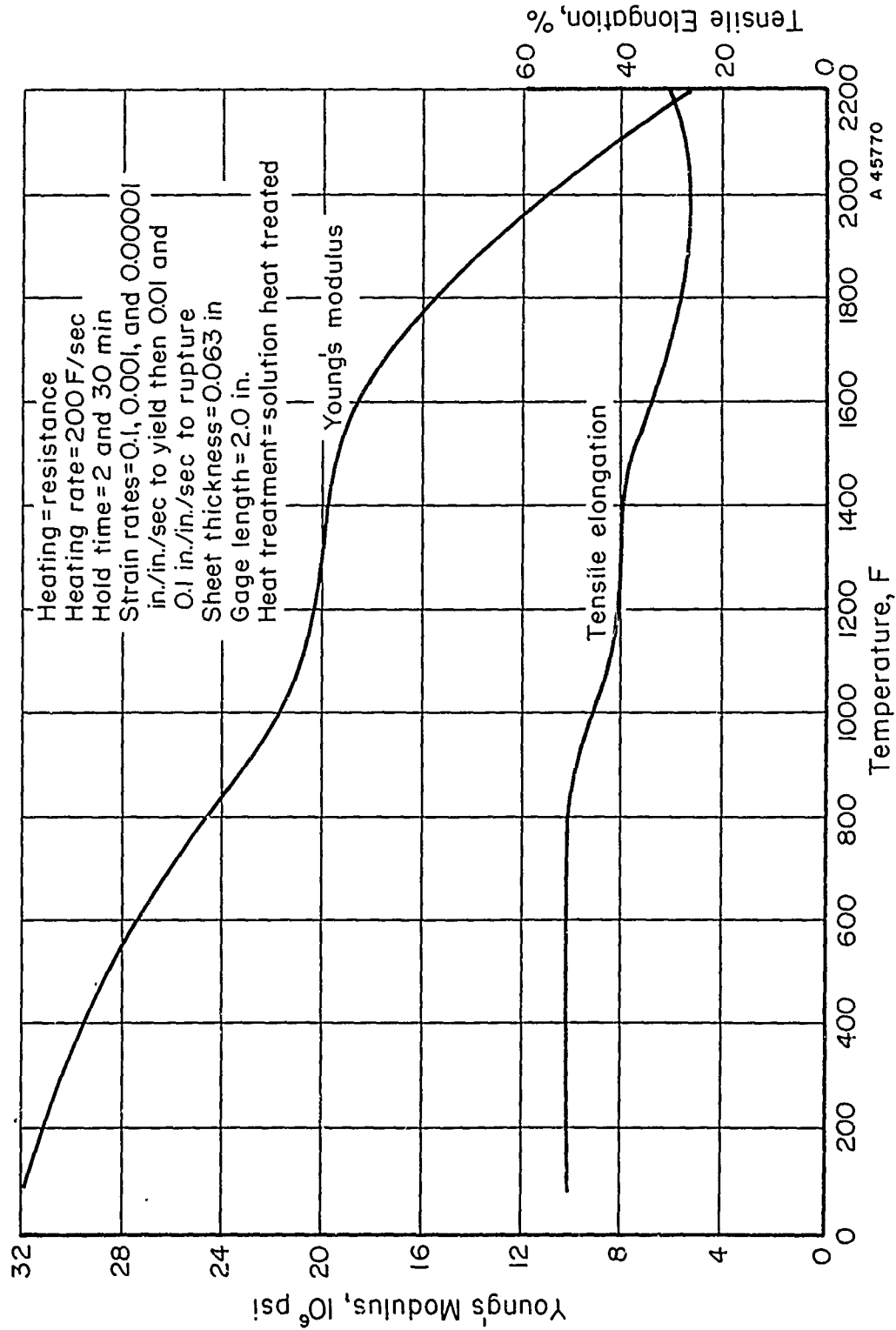


FIGURE 23. TYPICAL TENSILE ELONGATION AND MODULUS OF ELASTICITY (Co-20Cr-15W-10Ni)

Reference 29.

TABLE 53. TENSILE PROPERTIES OF ANNEALED SHEET AT DIFFERENT TEMPERATURES, HOLDING TIMES, AND STRAIN RATES (Co-20Cr-15W-10Ni)^(a)

References 5 and 30.

Temperature, F	Time at Temperature, sec	Strain Rate, in./in./sec	Proportional Limit, ksi	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Modulus of Elasticity, 10 ⁶ psi	Elongation, %
90	--	0.000045	19.8	135.6	60.4	38.3	40.8
80	--	0.0113	31.3	139.1	69.9	36.6	59.7
80	--	0.83	39.5	130.3	77.3	37.3	44.5
400	10	0.000060	12.4	121.1	42.2	29.4	57.7
400	10	0.0102	32.4	119.3	48.6	28.5	59.5
400	10	1.34	18.9	117.2	52.0	21.6	53.0
400	1800	0.000061	15.9	127.2	44.3	30.5	59.7
400	1800	0.0095	36.4	116.2	51.2	26.8	57.0
400	1800	1.15	40.2	114.8	53.1	19.5	57.5
800	10	0.000047	29.0	110.7	37.8	21.0	52.5
800	10	0.0145	27.0	107.0	38.7	20.1	62.0
800	10	1.08	34.4	105.3	47.5	21.6	51.2
800	1800	0.000060	27.5	108.2	36.6	23.0	56.8
800	1800	0.0125	25.9	102.3	36.5	23.9	54.8
800	1800	1.18	35.7	106.6	46.3	22.1	49.5
1200	10	0.000057	25.8	80.9	36.2	27.1	21.8
1200	10	1.11	23.3	82.1	36.3	18.5	51.0
1200	1800	0.000058	29.1	81.4	38.1	28.2	16.7
1200	1800	1.03	27.9	83.1	37.1	18.5	57.2
1600	10	0.000052	22.2	36.5	34.8	18.4	13.3
1600	10	0.0090	30.7	61.7	33.3	21.4	25.3
1600	10	0.96	26.1	72.8	32.2	19.7	40.2
1600	1800	0.000044	20.3	35.1	32.8	21.6	12.8
1600	1800	0.0098	28.5	61.3	32.7	20.6	28.0
1600	1800	1.04	28.4	73.6	30.8	17.8	48.0
2000	10	0.000058	3.4	6.4	6.2	7.2	7.0
2000	10	0.0112	16.4	22.7	22.2	14.3	21.3
2000	10	0.97	24.8	45.1	27.3	14.7	32.0
2000	1800	0.000058	3.7	6.5	6.1	8.6	10.7
2000	1800	0.0083	15.6	24.4	24.2	18.2	17.5
2000	1800	0.91	22.9	45.7	27.0	17.2	33.2
2250	10	0.000056	2.7	4.6	4.2	7.1	7.8
2250	10	0.0106	8.0	11.5	11.5	11.6	18.5
2250	10	1.13	21.6	26.6	24.2	18.2	38.2
2250	100	0.0115	9.6	13.7	13.5	11.6	16.3
2250	1800	0.000047	3.1	4.6	4.2	7.5	9.0
2250	1800	0.0097	11.1	15.5	15.5	14.6	19.8
2250	1800	1.15	20.1	26.8	21.8	18.5	29.2

(a) 0.040-in. sheet, tested in transverse direction. Results are average of two or three determinations.
Resistance heated to test temperature within 10 seconds.

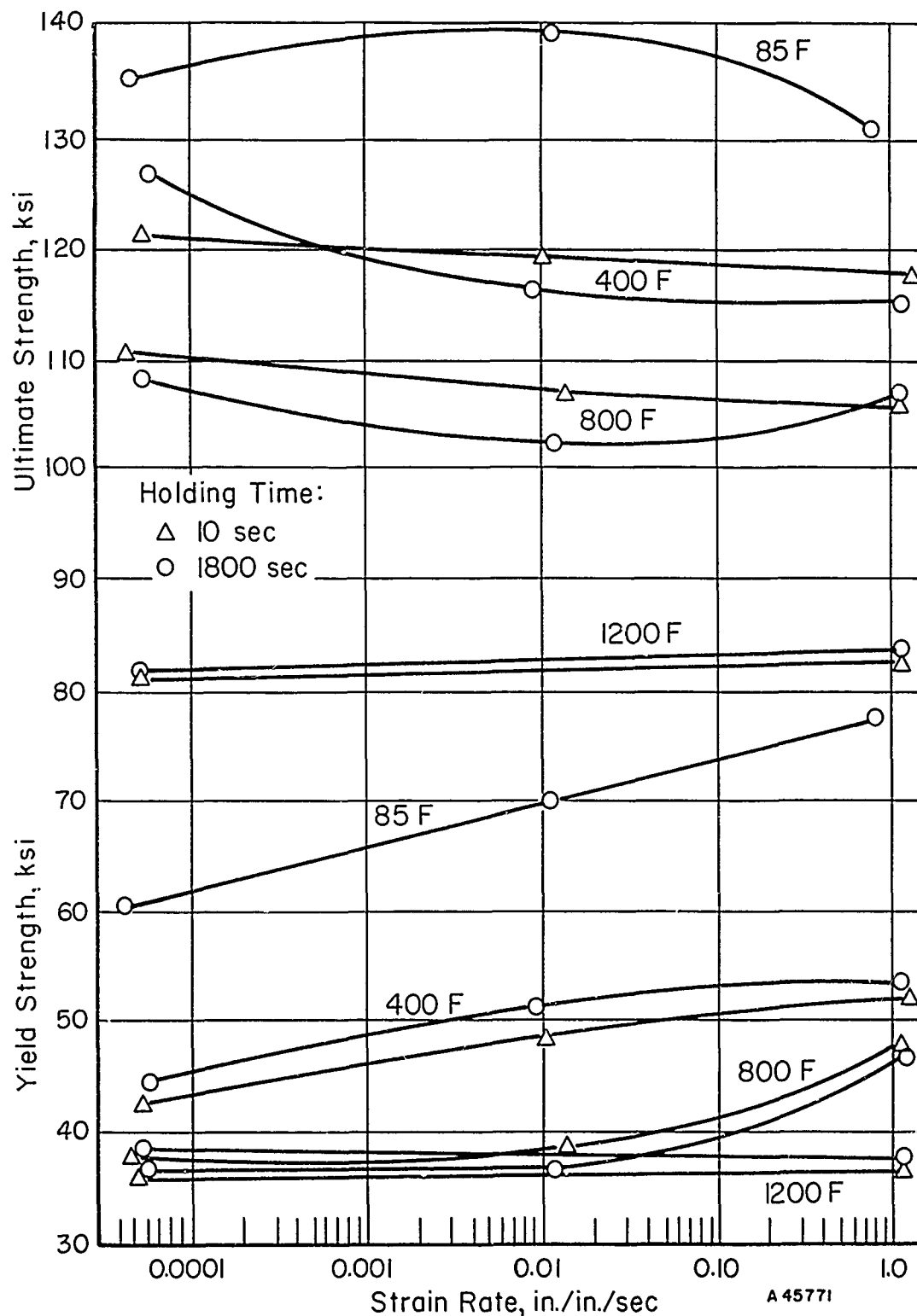


FIGURE 24. EFFECT OF STRAIN RATE ON THE ULTIMATE TENSILE STRENGTH AND 0.2% OFFSET YIELD STRENGTH OF ANNEALED 0.040-IN. SHEET AT DIFFERENT TEMPERATURES AND HOLDING TIMES (Co-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 seconds.

Reference 5.

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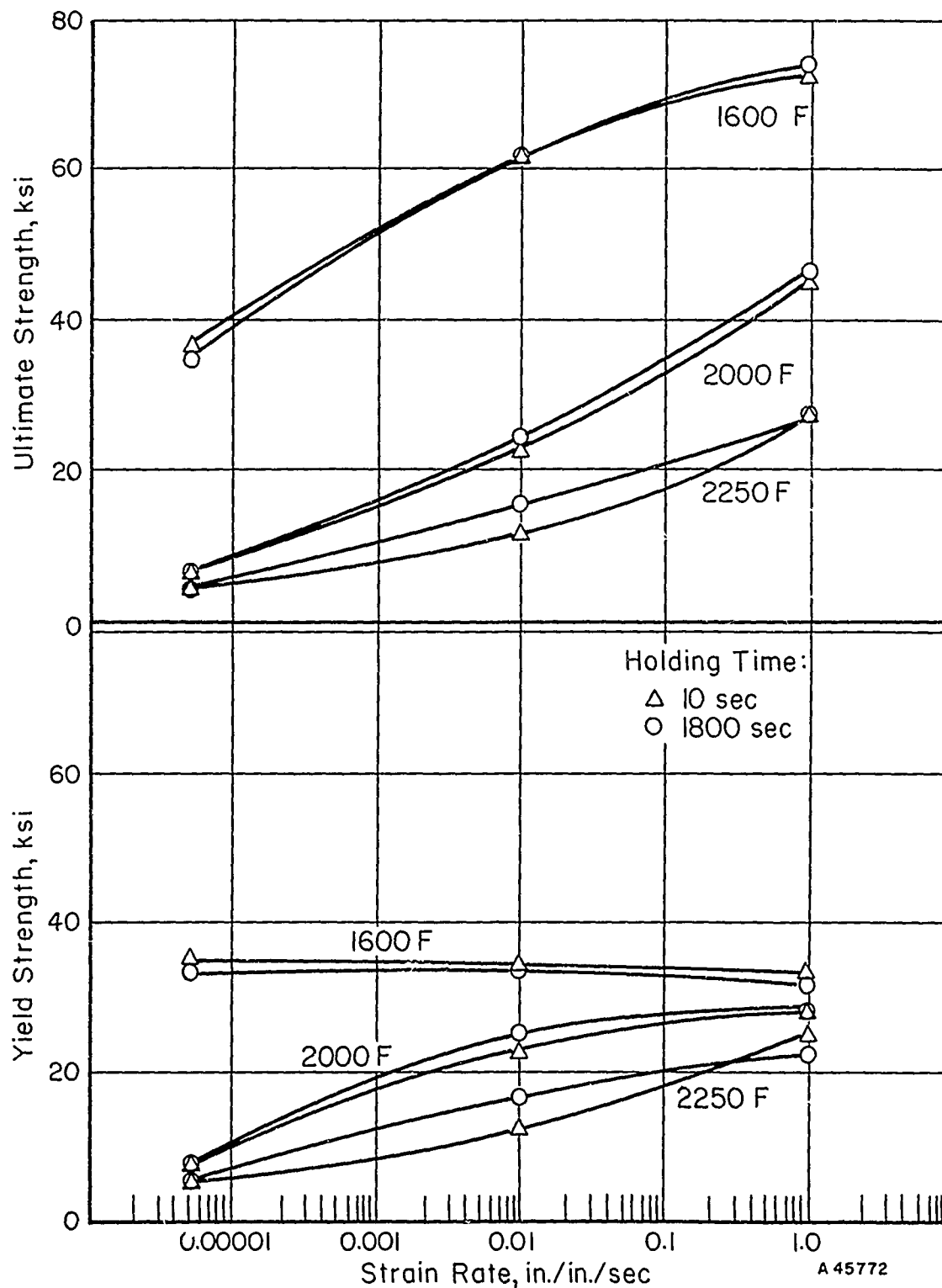


FIGURE 25. EFFECT OF STRAIN RATE ON THE 0.2% OFFSET YIELD STRENGTH AND ULTIMATE TENSILE STRENGTH OF ANNEALED 0.040-IN. SHEET AT DIFFERENT TEMPERATURES AND HOLDING TIMES (Co-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 seconds.

Reference 30.

BATTELLE MEMORIAL INSTITUTE

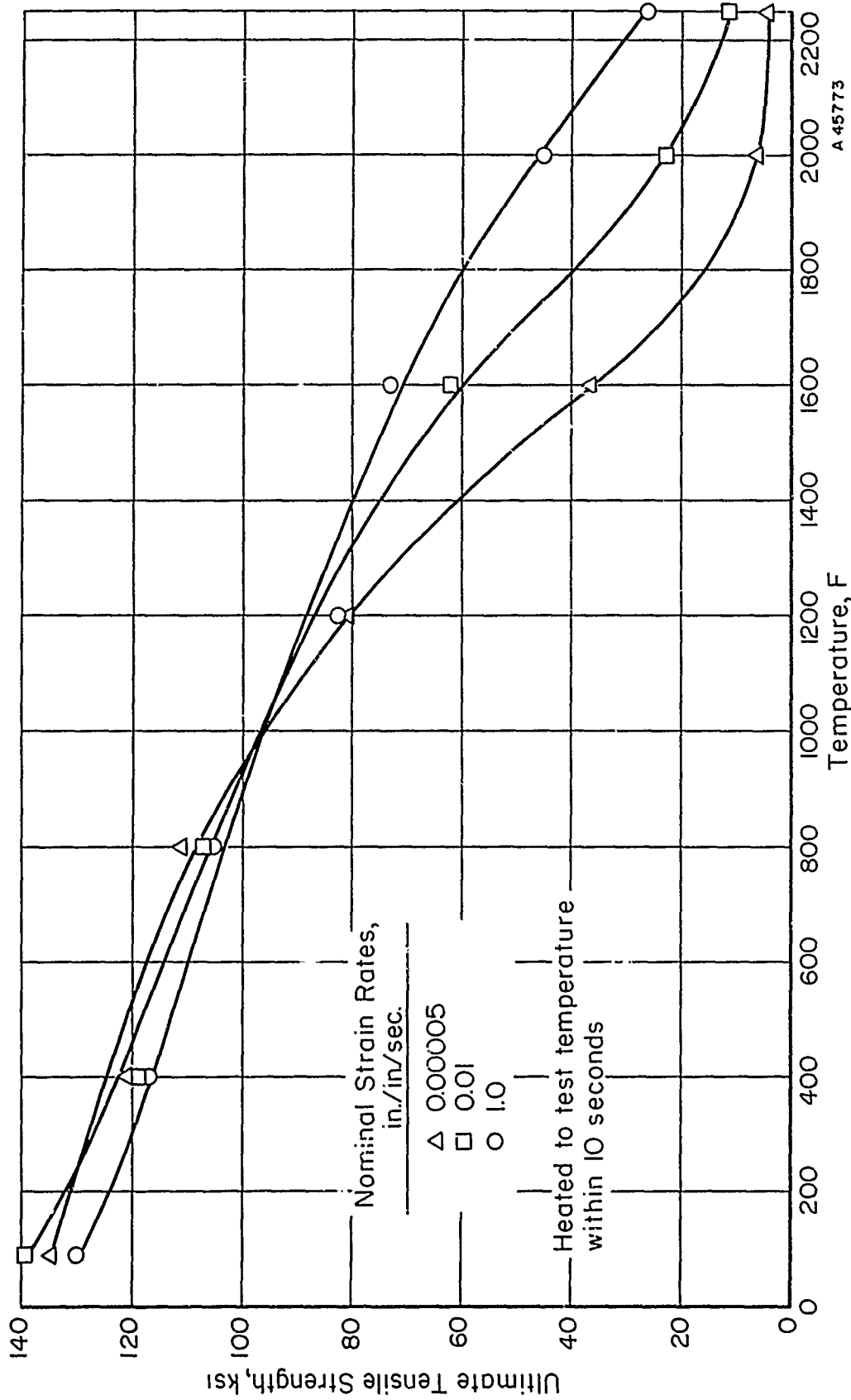


FIGURE 26. EFFECT OF TEMPERATURE, AFTER 10-SEC HOLDING TIME, ON THE ULTIMATE TENSILE STRENGTH OF ANNEALED 0.040-IN. -THICK SHEET AT DIFFERENT STRAIN RATES (Co-20Cr-15W-10Ni)

Reference 31.

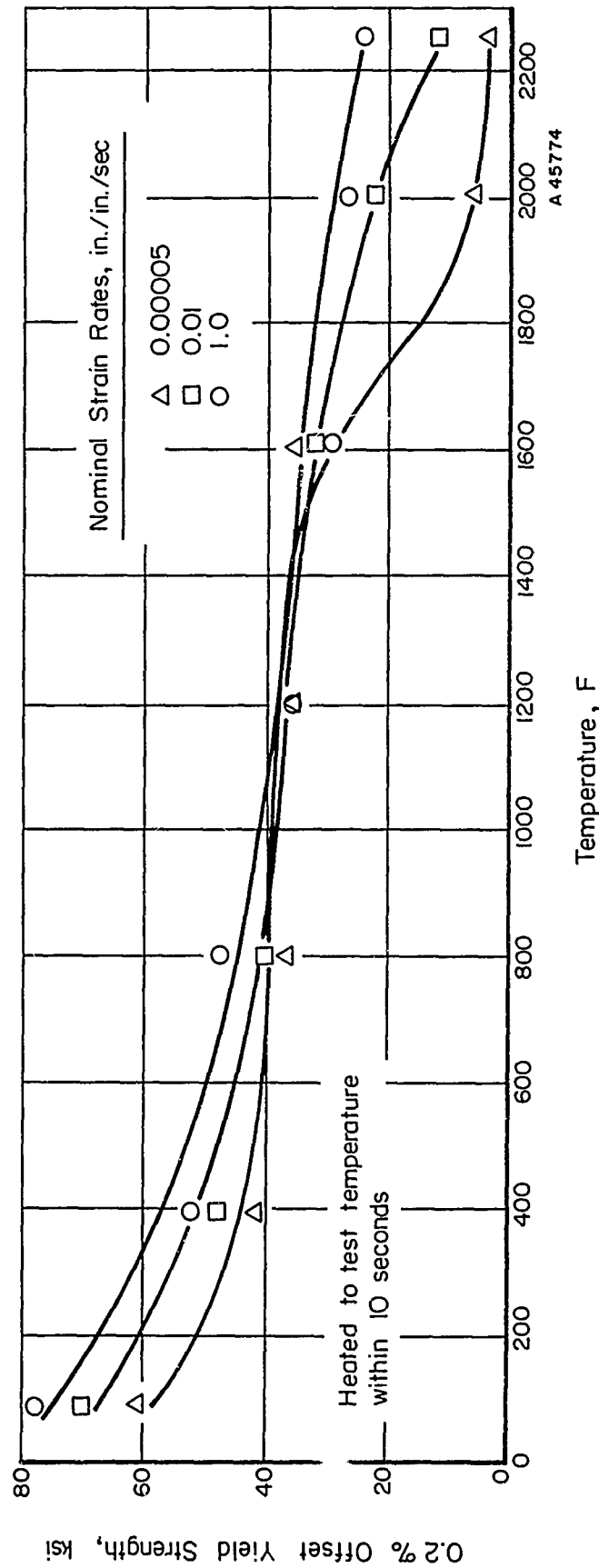


FIGURE 27. EFFECT OF TEMPERATURE, AFTER 10-SEC HOLDING TIME, ON THE 0.2% OFFSET YIELD STRENGTH OF ANNEALED 0.040-IN.-THICK SHEET AT DIFFERENT STRAIN RATES (Co-20Cr-15W-10Ni)

Reference 31.

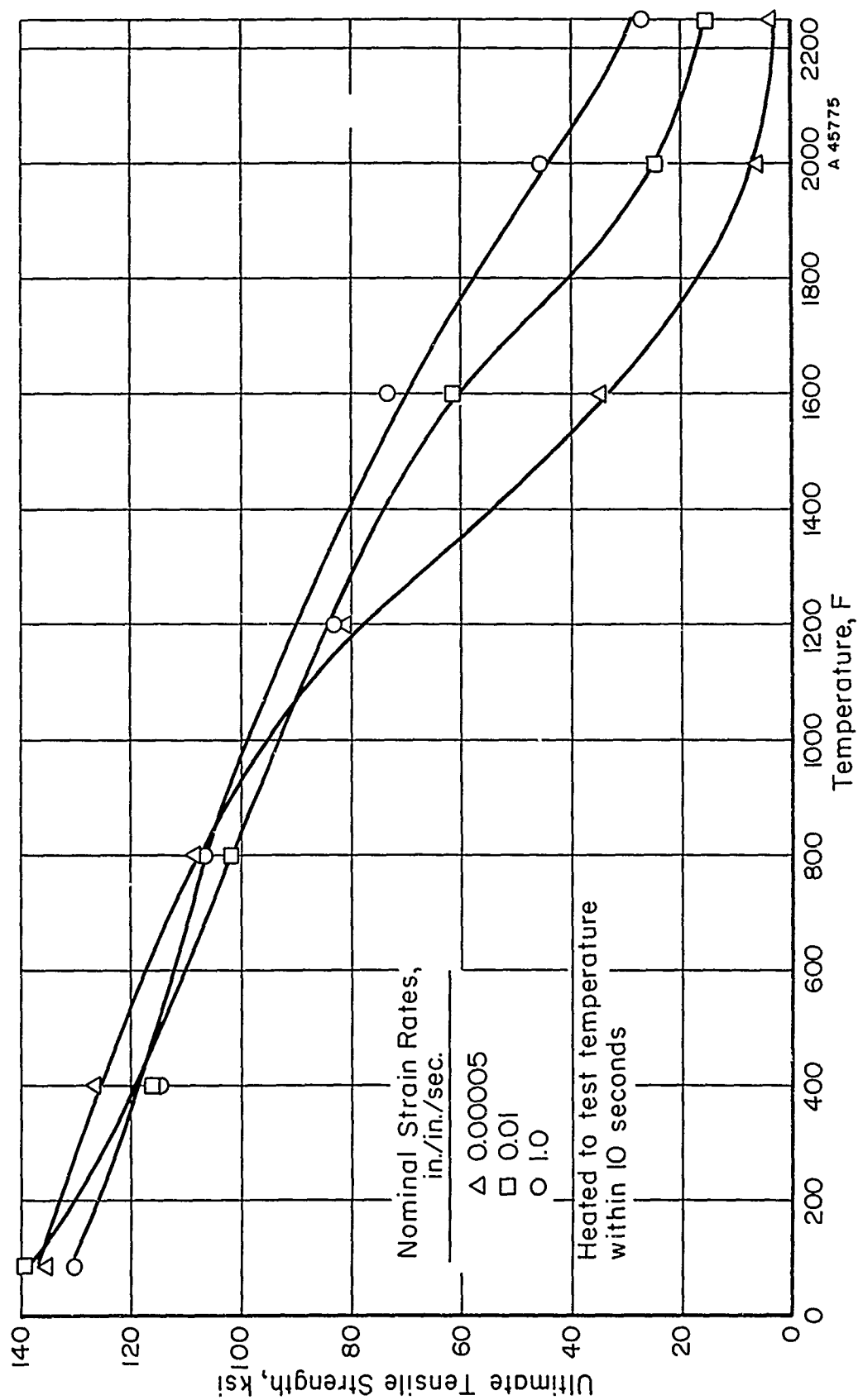


FIGURE 28. EFFECT OF TEMPERATURE, AFTER 1800-SEC HOLDING TIME, ON THE ULTIMATE TENSILE STRENGTH OF ANNEALED 0.040-IN.-THICK SHEET AT DIFFERENT STRAIN RATES (Co-20Cr-15W-10Ni)

References 5, 30.

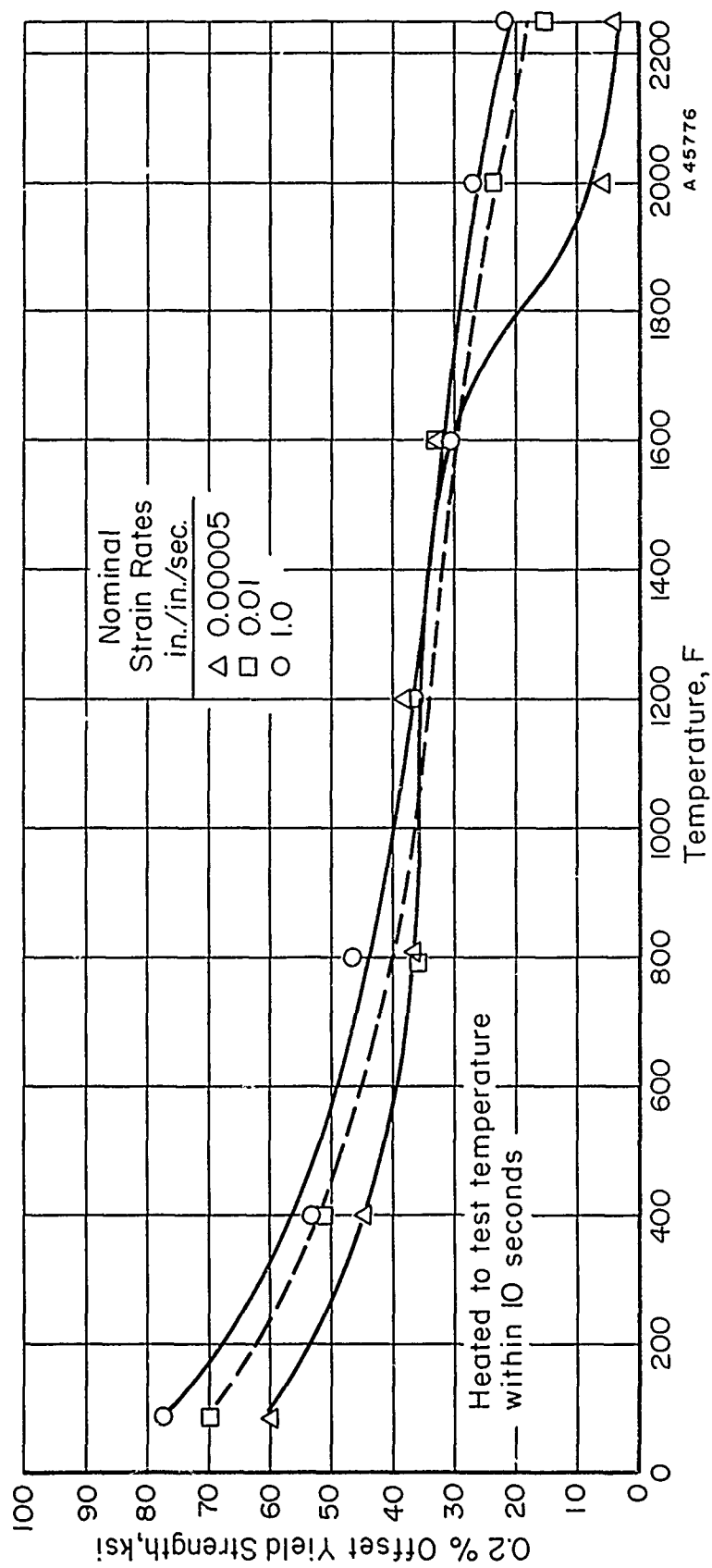


FIGURE 29. EFFECT OF TEMPERATURE, AFTER 1800-SEC HOLDING TIME, ON THE 0.2% OFFSET YIELD STRENGTH OF ANNEALED, 0.040-IN.-THICK SHEET AT DIFFERENT STRAIN RATES (Co-20Cr-15W-10Ni)

References 5, 30.

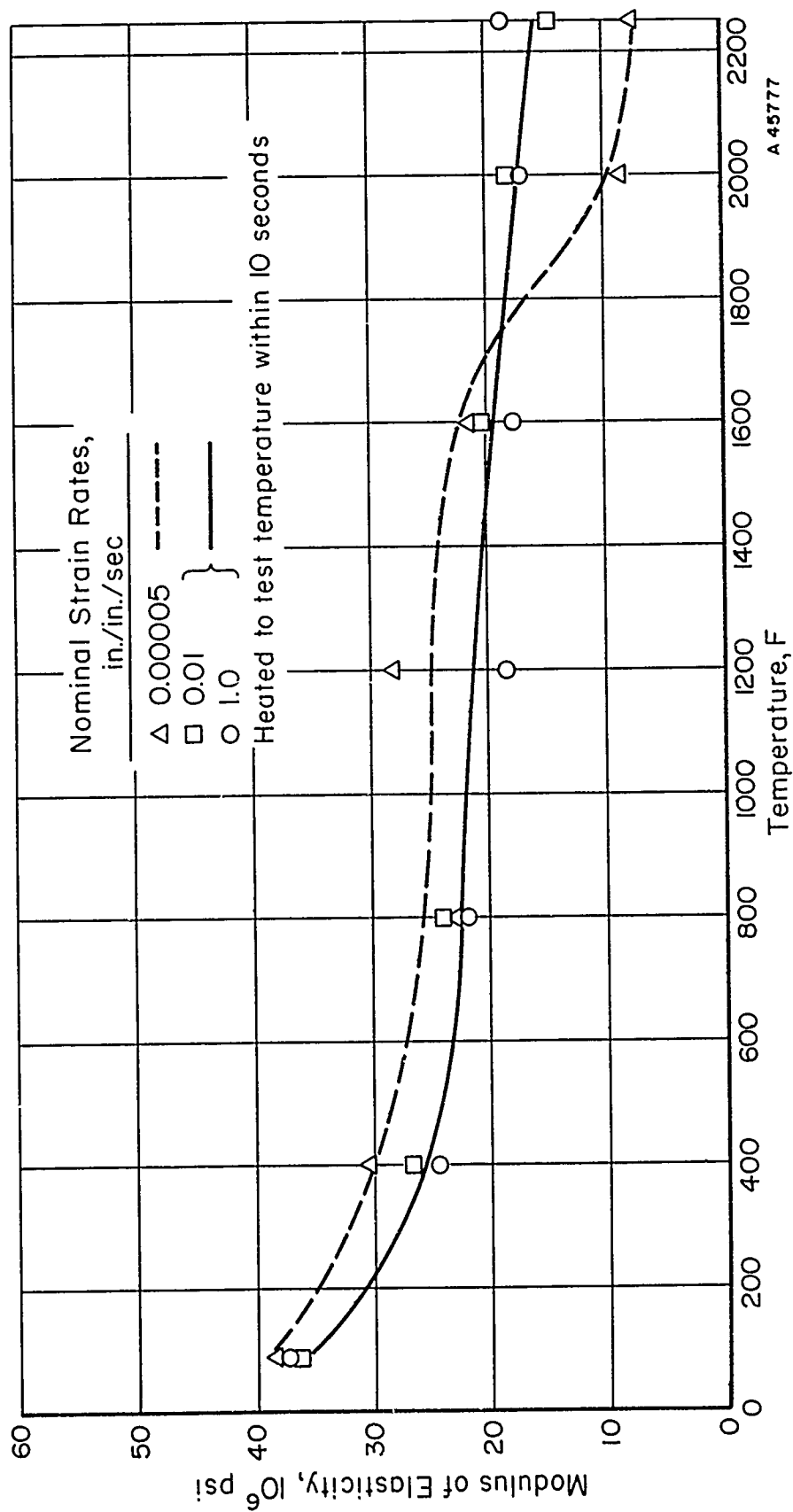


FIGURE 30. EFFECT OF TEMPERATURE, AFTER 1800-SEC HOLDING TIME ON THE MODULUS OF ELASTICITY OF 0.040-IN. SHEET, TESTED AT DIFFERENT STRAIN RATES (Co-20Cr-15W-10Ni)

References 5, 30.

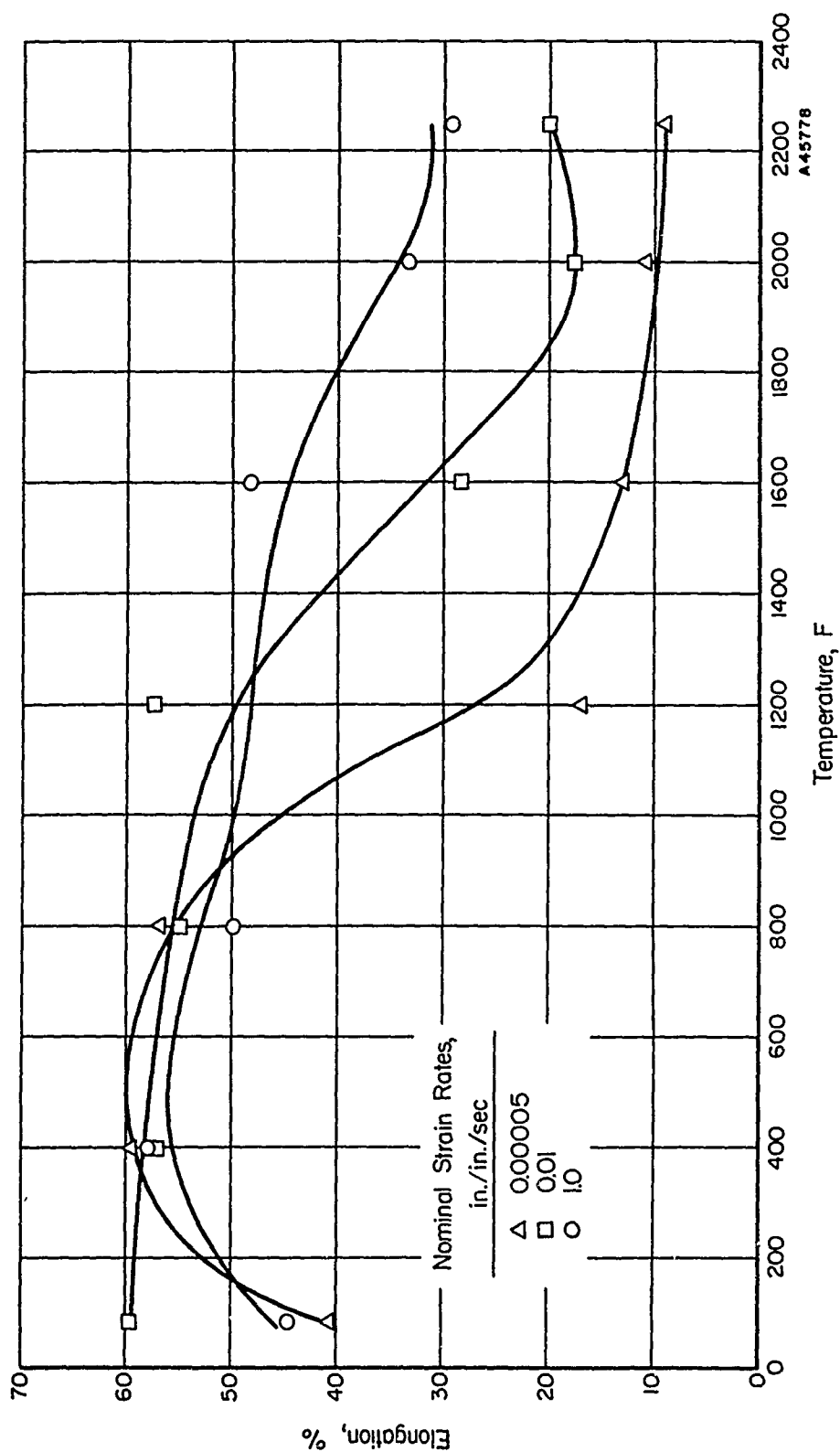


FIGURE 31. EFFECT OF TEMPERATURE AFTER 1800-SEC HOLDING TIME, ON THE ELONGATION OF 0.040-IN. SHEET, TESTED AT DIFFERENT STRAIN RATES (Co-20Cr-15W-10Ni)

Heated to test temperature within 10 seconds.

References 5, 30.

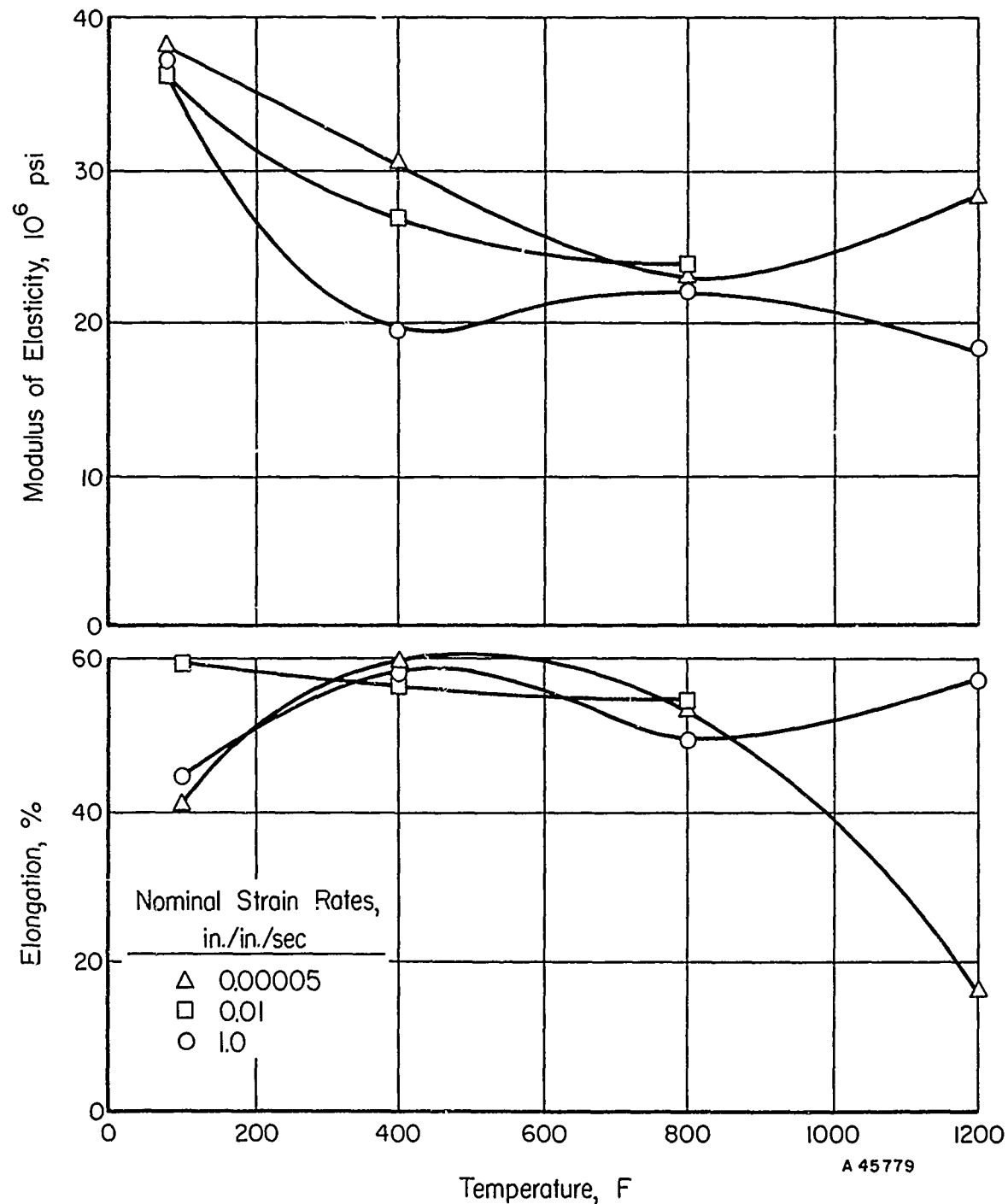


FIGURE 32. EFFECT OF TEMPERATURE, AFTER 1800-SEC HOLDING TIME, ON THE ELONGATION AND MODULUS OF ELASTICITY OF ANNEALED 0.040-IN. SHEET AT DIFFERENT STRAIN RATES (Co-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 seconds.

Reference 5.

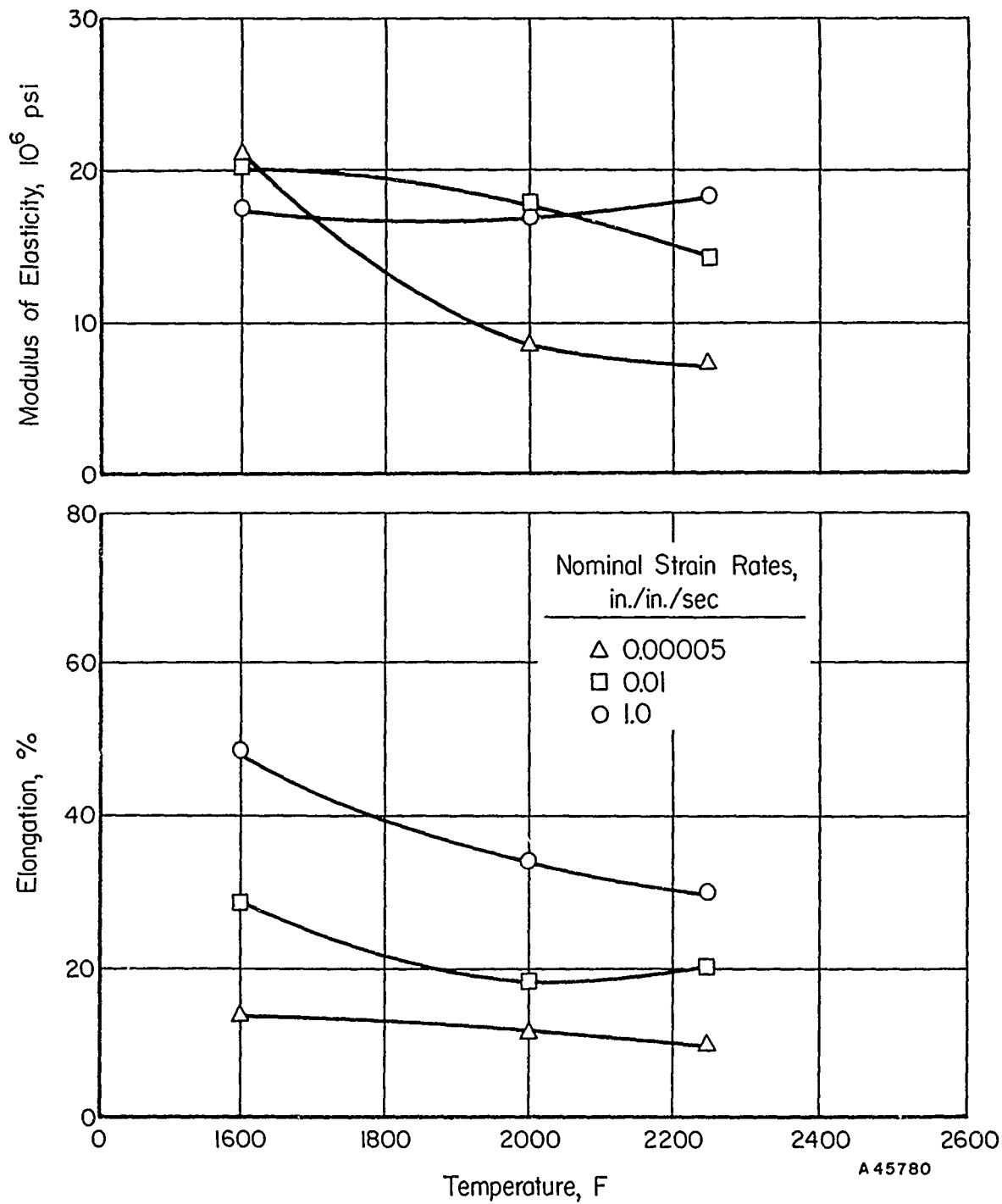


FIGURE 33. EFFECT OF TEMPERATURE, AFTER 1800-SEC HOLDING TIME, ON THE PER CENT ELONGATION AND MODULUS OF ELASTICITY OF ANNEALED 0.040-IN. SHEET AT DIFFERENT STRAIN RATES (C0-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 sec.

Reference 30.

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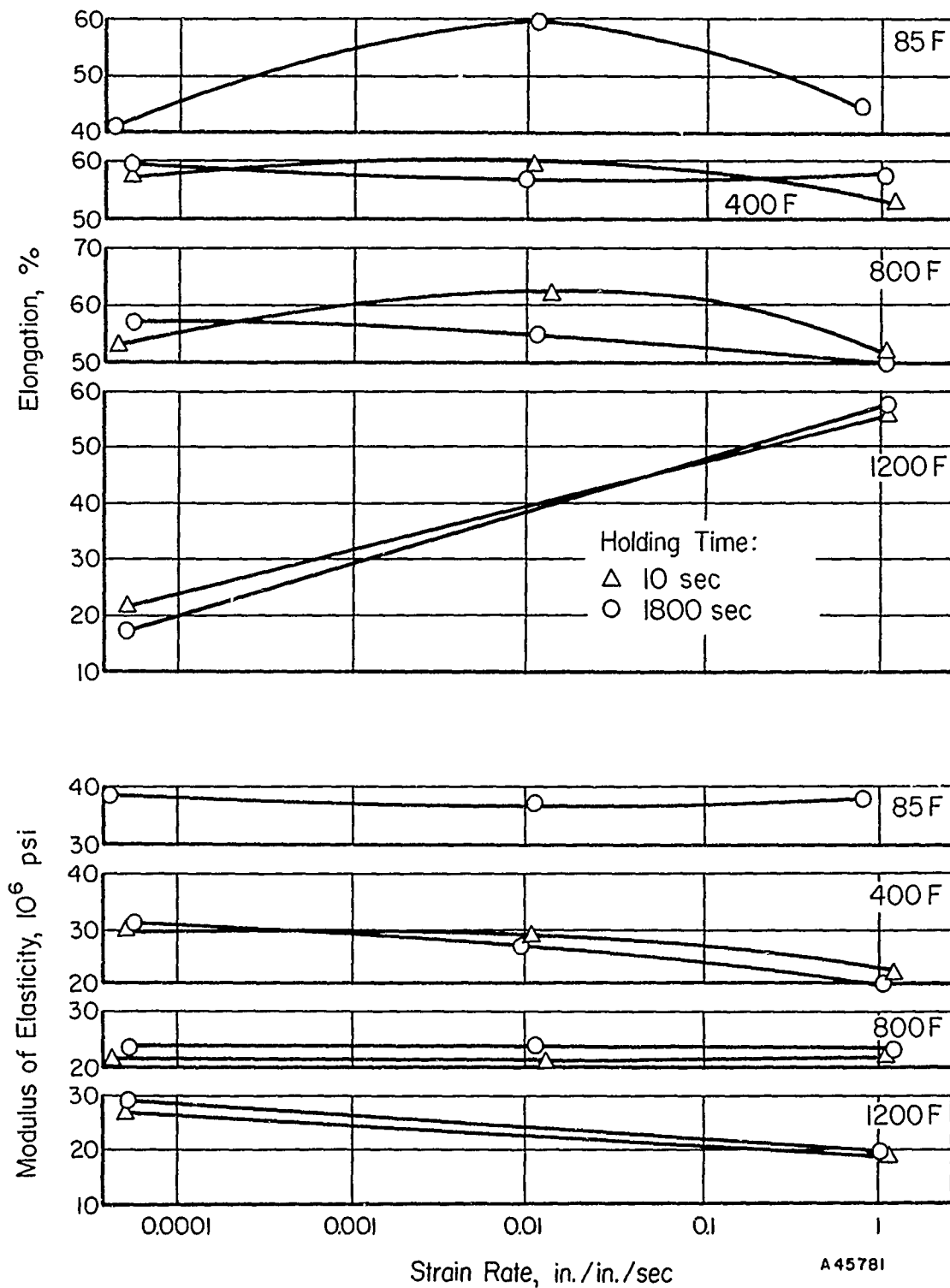


FIGURE 34. EFFECT OF STRAIN RATE ON THE PER CENT ELONGATION AND MODULUS OF ELASTICITY OF ANNEALED 0.040-IN. SHEET AT DIFFERENT TEMPERATURES AND HOLDING TIMES (Co-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 sec.

Reference 5.

BATTELLE MEMORIAL INSTITUTE

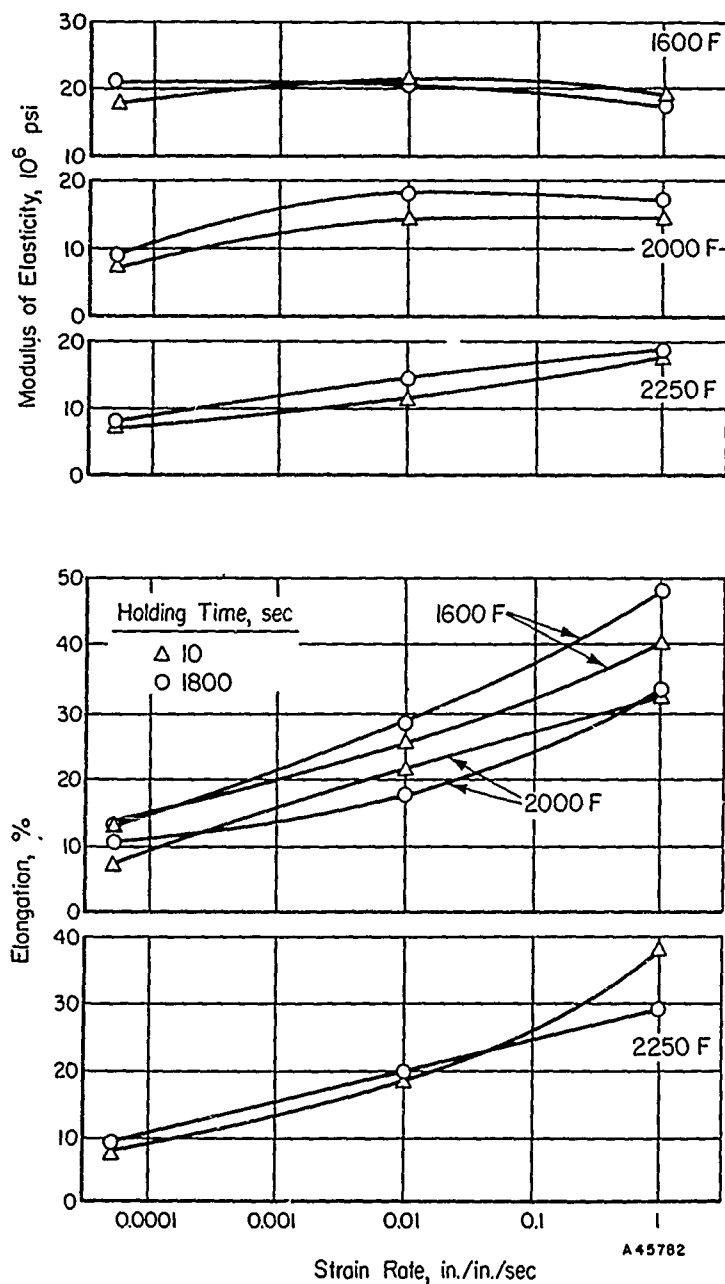


FIGURE 35. EFFECT OF STRAIN RATE ON THE PER CENT ELONGATION AND MODULUS OF ELASTICITY OF ANNEALED 0.040-IN. SHEET AT DIFFERENT TEMPERATURES AND HOLDING TIMES (Co-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 seconds.

Reference 30.

BATTELLE MEMORIAL INSTITUTE

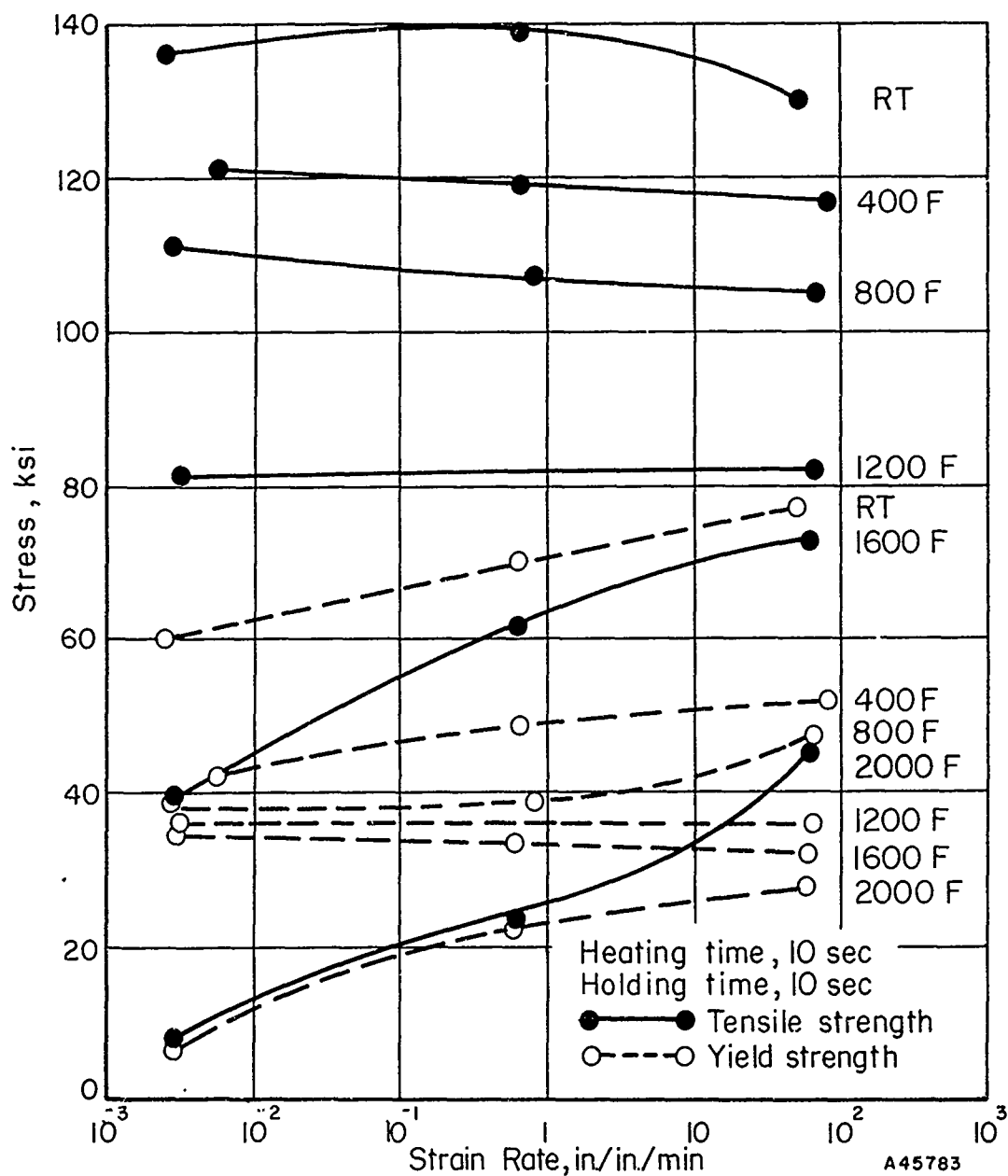


FIGURE 36. EFFECT OF STRAIN RATE ON THE TENSILE PROPERTIES OF ANNEALED SHEET (Co-20Cr-15W-10Ni)

0.040-in.-thick sheet, tested in transverse direction.

Reference 32.

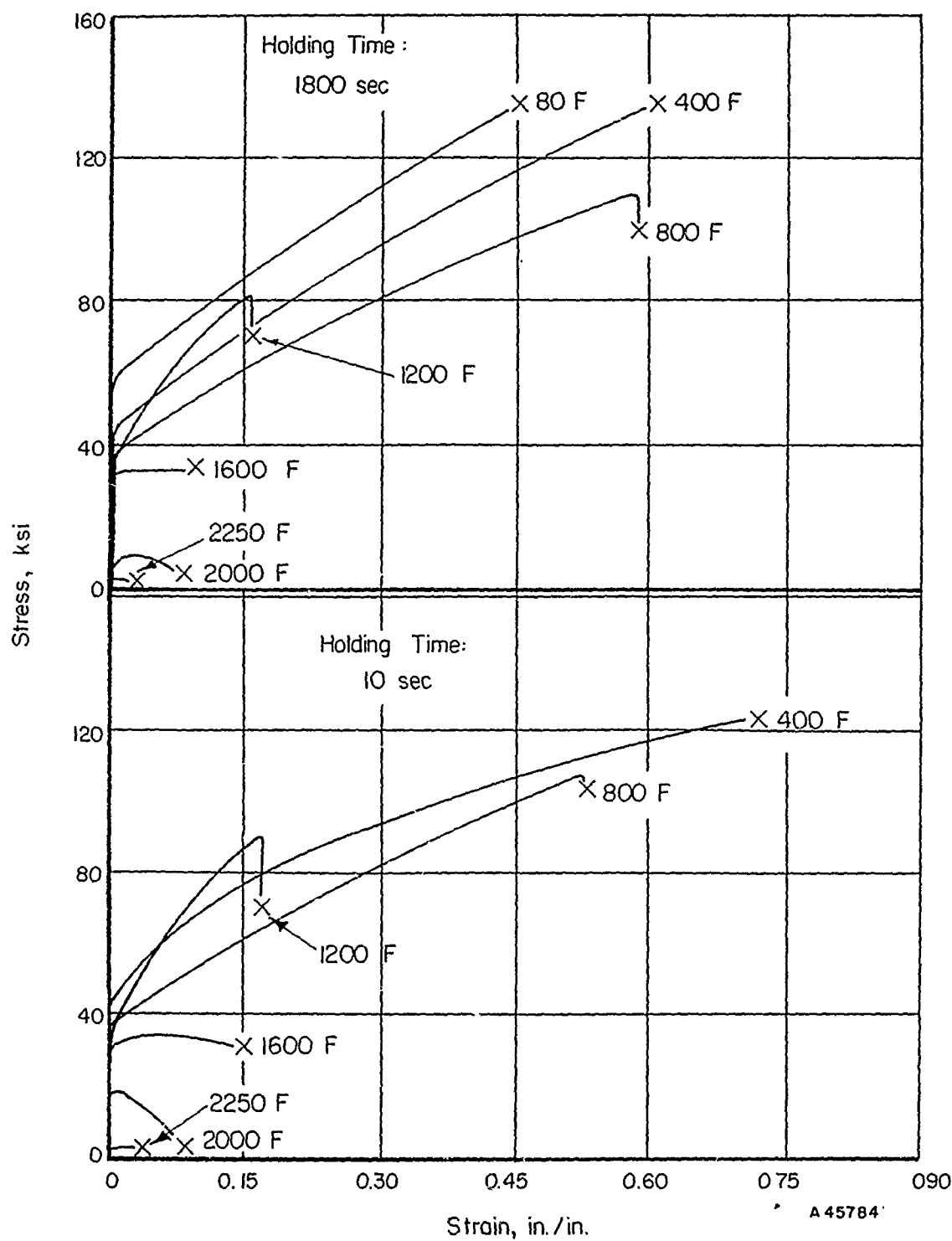


FIGURE 37. COMPLETE STRESS-STRAIN CURVES AT DIFFERENT TEMPERATURES AND HOLDING TIMES AND AT 0.00005 IN./IN./SEC STRAIN RATE (Co-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 sec. Annealed 0.040-in. sheet.

Reference 33.

BATTELLE MEMORIAL INSTITUTE

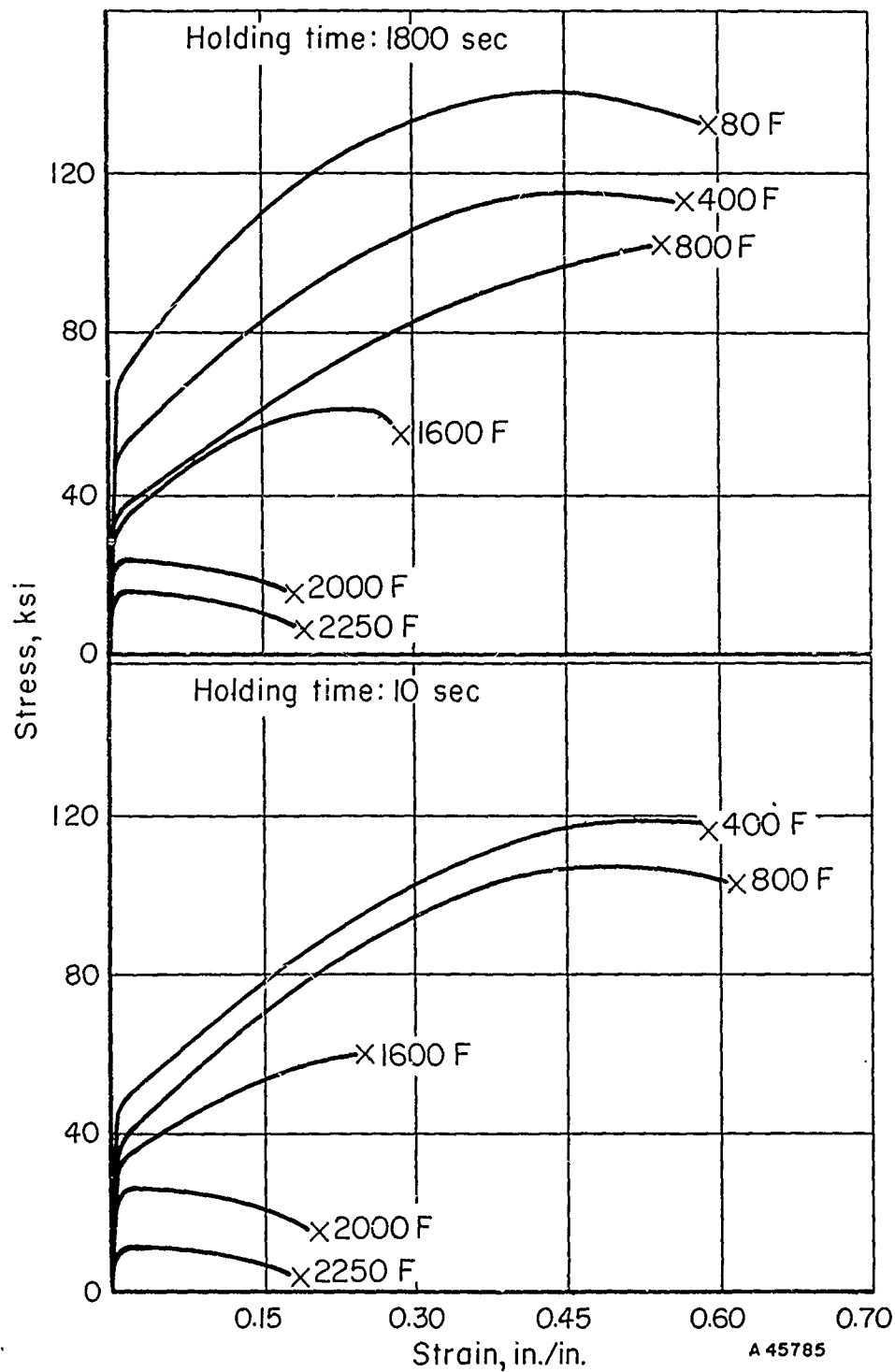


FIGURE 38. COMPLETE STRESS-STRAIN CURVES AT DIFFERENT TEMPERATURES AND HOLDING TIMES AND AT 0.01 IN./IN./SEC STRAIN RATE (Co-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 sec. Annealed 0.040-in. sheet.

Reference 33.

BATTELLE MEMORIAL INSTITUTE

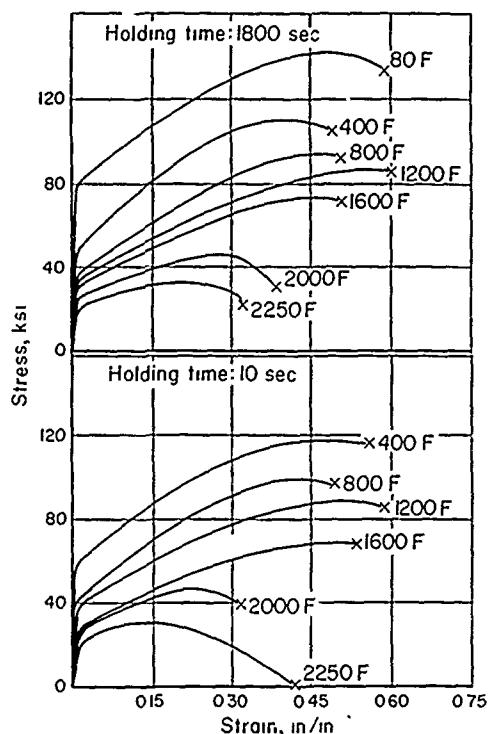


FIGURE 39. COMPLETE STRESS-STRAIN CURVES AT DIFFERENT TEMPERATURES AND HOLDING TIMES AND AT 1.0 IN. /IN. /SEC STRAIN RATE (Co-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 sec. Annealed 0.040-in. sheet.

Reference 33.

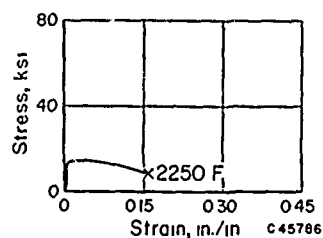


FIGURE 40. COMPLETE STRESS-STRAIN CURVE AT 2250 F, 0.01 IN. /IN. /SEC STRAIN RATE, AND 100-SEC HOLDING TIME (Co-20Cr-15W-10Ni)

Specimens were heated to test temperature within 10 sec. Annealed 0.040-in. sheet.

Reference 33.

BATTELLE MEMORIAL INSTITUTE

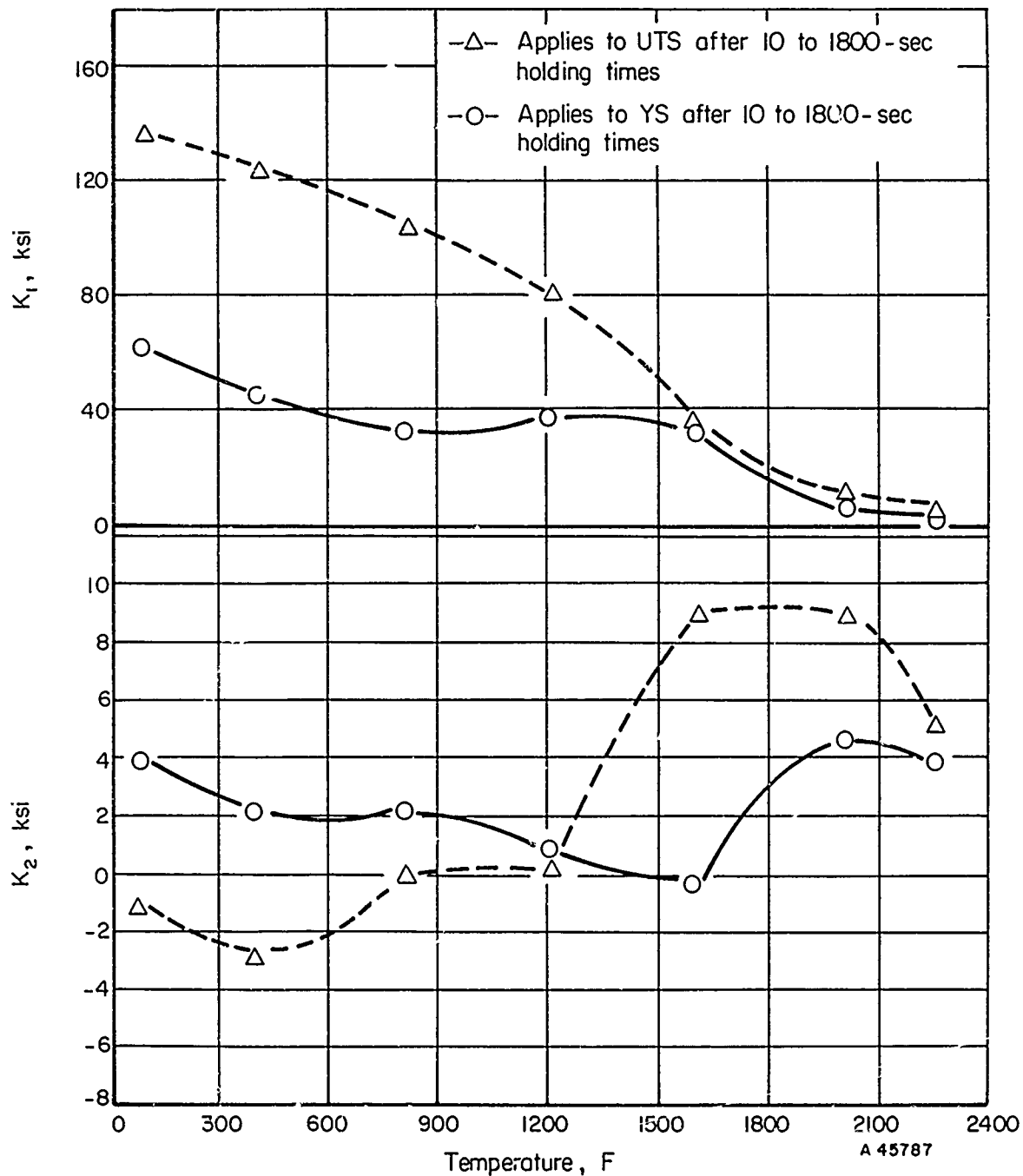


FIGURE 41. EFFECT OF TEMPERATURE, AFTER 10-SEC HEATING TIME AND HOLDING TIMES FROM 10 TO 1800 SEC, ON CONSTANTS K_1 AND K_2 FOR THE DETERMINATION OF 0.2% OFFSET STRENGTH AND ULTIMATE TENSILE STRENGTH OF ANNEALED SHEET BY THE FORMULA, $\text{STRENGTH} = K_1 + K_2 (\text{Log } r + 4.3)$

Data applies to range of strain rates (r) from 0.00005 to 1.0 in./in./sec.

Reference 31.

TABLE 54. EFFECT OF TEMPERATURE ON TENSILE PROPERTIES
(Co-20Cr-15W-10Ni)^(a)

0.062-in. sheet, longitudinal axis parallel to direction of rolling. Solution annealed 10 min at 2200 F, air cooled and pickled. Held at testing temperature 30 to 45 min before testing at 0.050 to 0.060 in./in./min.

Reference 28.

Test Temperature, F	Tensile Strength, ksi	Yield Strength, ksi		Elongation, %
		0.2% Offset	0.02% Offset	
Room	160.7	85.8	61.0	47.0
750	138.0	55.9	47.5	47.0
1000	130.6	53.9	51.9	40.0
1200	94.0	54.9	53.1	29.0
1350	83.8	51.3	48.3	11.0
1500	55.3	44.9	39.8	16.0
1650	34.2	31.9	27.6	30.0
1800	29.2	27.5	25.8	37.0

(a) Average of two samples tested at each temperature.

TABLE 55. SHORT-TIME ELEVATED-TEMPERATURE TENSILE PROPERTIES OF SHEET (Co-20Cr-15W-10Ni)

Specimens heated by resistance-wound furnace and held at temperature for 30 min before application of load.

Reference 7.

Heat	Sheet Gage	Direction (a)	Test Temperature, °F	Ultimate Tensile Strength, ksi (b)	0.2% Offset Yield Strength, ksi (b, c)	Modulus (b), 10 ⁶ psi	Elongation in 2 in. (b), %
A	0.020	L	600	111.6(5)	44.0(4)	30.8(4)	60.2(5)
A	0.020	L	1000	98.6(5)	42.5(4)	18.7(3)	59.6(5)
A	0.020	T	600	109.9(5)	42.7(4)	28.6(4)	60.7(5)
A	0.020	T	1000	96.8(5)	41.3(3)	22.5(3)	58.3(5)
A	0.040	L	400	124.5(5)	53.3(4)	27.4(4)	69.5(5)
A	0.040	L	600	114.9(4)	41.8(4)	22.9(3)	70.5(4)
A	0.040	L	800	109.3(4)	40.3(4)	19.3(3)	68.8(4)
A	0.040	T	400	120.8(3)	48.0(3)	--	63.7(3)
A	0.040	T	600	114.5(4)	40.2(4)	21.3(3)	67.5(4)
A	0.040	T	800	108.4(4)	39.7(4)	21.2(2)	63.9(4)

(a) L - longitudinal; T - transverse.

(b) Results reported are the averages of the number of tests noted in parentheses.

(c) Strain rate of 0.005 in./in./min to the yield point, then crosshead speed of 0.060 in./min to fracture.

TABLE 56. SHORT-TIME TENSILE PROPERTIES OF 0.077-GAGE, MILL-ANNEALED SHEET (Co-20Cr-15W-10Ni)

Strain rate: 0.001 in./in./sec to yield strength, than 0.01 in./in./sec to rupture.

Reference 34.

Test Temperature, F	Soak, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Modulus of Elasticity, 10 ⁶ psi	Hardness, Rockwell B
RT	--	55.0	72.0	136.0	59	32.0	99
RT	--	--	--	140.0	65	--	99
1200	1	22.0	34.8	91.5	55	22.0	98
1200	1	23.0	34.2	95.9	60	21.0	
1200	15	24.0	34.0	90.0	66	22.0	99
1200	15	31.0	36.8	101.0	70	20.8	99
1600	15	26.0	31.5	62.8	31	18.5	99
1600	15	21.0	29.0	59.5	40	16.8	98
1800	15	22.8	29.0	39.2	35	13.0	99
1800	15	20.5	22.5	32.9	25	14.5	99
2100	15	11.5	7.8	15.0	25	6.2	99
2100	15	6.3	9.5	15.8	25	7.0	99

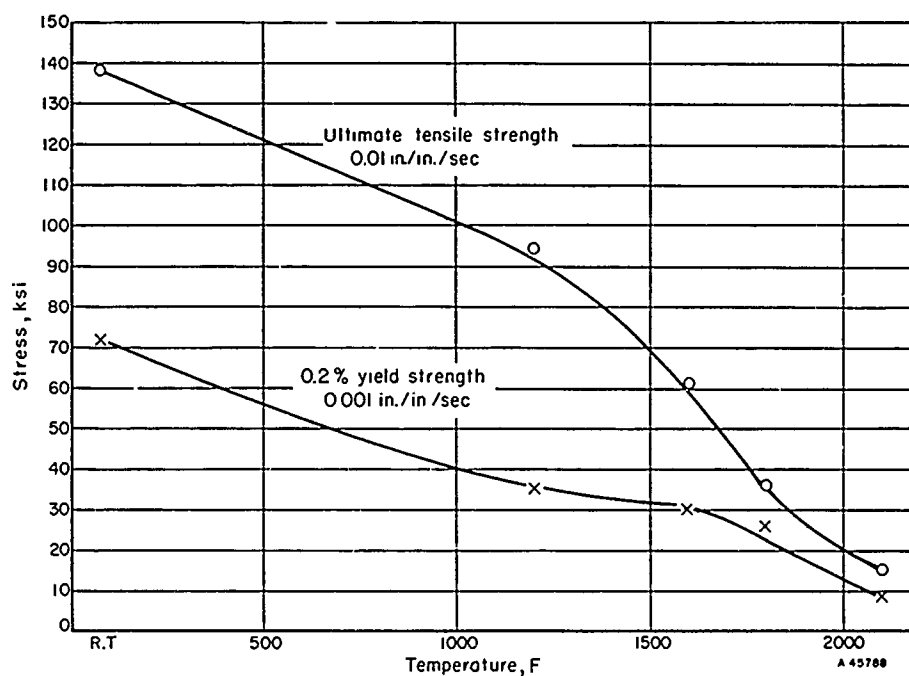


FIGURE 42. SHORT-TIME TENSILE DATA FOR 0.077-GAGE MILL-ANNEALED SHEET (Co-20Cr-15W-10Ni)

Reference 34.

TABLE 57. EFFECT OF VARIOUS HEAT TREATMENTS ON ROOM-TEMPERATURE AND 1600 F TENSILE PROPERTIES OF 0.063-IN. SHEET (Co-20Cr-15W-10Ni)

Tested at 0.005 in./in./min on 1-in. gage length specimens.

Reference 9 - Section A. 6.

Aging Conditions	Test Temperature, F	Ultimate Tensile Strength, ksi	0.02% Offset Yield Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation, %
1000 hr at 1600 F	1600	39.5	26.2	23.0	41.0
4 hr at 2100 and 1000 hr at 1600 F	1600	37.9	24.7	30.2	46.3
1000 hr at 1600 F	RT	142.0	60.5	81.7	5
1000 hr at 1600 F, with cycling to 1850 F, 2 hr out of every 24	RT	127.5	46.5	62.3	9
Ditto	1000	103.3	30.0	46.5	16.5

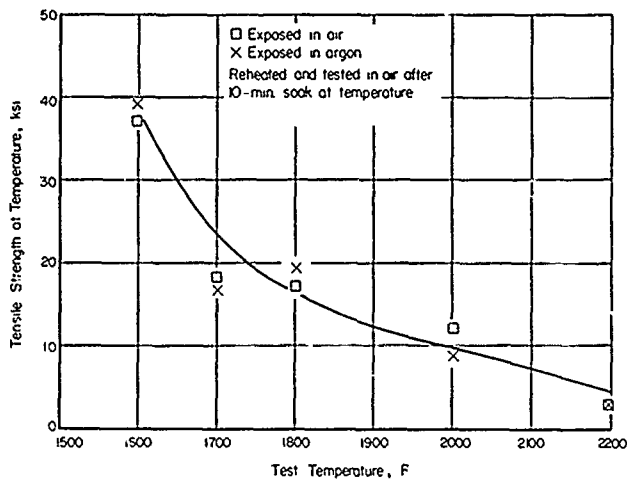


FIGURE 43. SHORT-TIME ELEVATED-TEMPERATURE TENSILE STRENGTH AFTER 1-HR PRIOR EXPOSURE AT TEST TEMPERATURE (Co-20Cr-15W-10Ni)

0.005-in.-thick foil.

Reference 11.

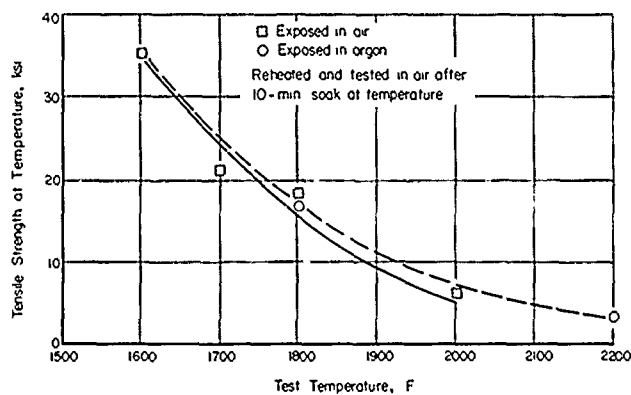


FIGURE 44. SHORT-TIME ELEVATED-TEMPERATURE TENSILE STRENGTH AFTER 24-HR PRIOR EXPOSURE AT TEST TEMPERATURE (Co-20Cr-15W-10Ni)

0.005-in.-thick foil.

Reference 11.

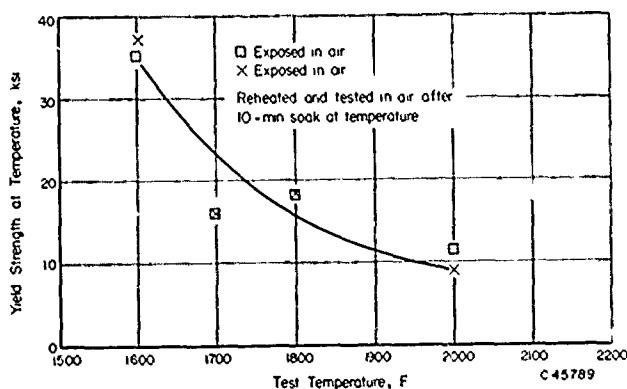


FIGURE 45. SHORT-TIME ELEVATED-TEMPERATURE YIELD STRENGTH (0.2% OFFSET) AFTER 1-HR PRIOR EXPOSURE AT TEST TEMPERATURE (Co-20Cr-15W-10Ni)

0.005-in.-thick foil.

Reference 11.

TABLE 58. SHORT-TIME TENSILE PROPERTIES AT 2000 F OF 0.020-IN. SHEET AFTER CYCLIC THERMAL EXPOSURE (Co-20Cr-15W-10Ni)

Five minutes to heat and stabilize before load was applied. Strain rate 0.002 in./in./min to the yield, then 0.03 in./in./min to failure.

Reference 6.

Exposure		Number of Cycles ^(a)	Test Temperature, F	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation in 2 In., %
Temperature, F	Time, hr					
2000	1	1	2000	11.6	10.9	10.0
2000	1	1	2000	10.6	9.4	10.0
2000	1	5	2000	9.5	8.3	9.0
2000	1	5	2000	11.0	9.7	11.0
2000	1	10	2000	9.7	9.0	10.0
2000	1	10	2000	10.1	9.1	13.0
2000(b)	1	1	2000	13.9		11.0
2000(b)	1	1	2000 ^(c)	12.3		10.0
2000(b)	1	1	2000 ^(c)	10.8	8.8	12.0
2000(b)	1	1	2000 ^(c)	11.1	9.3	12.0
2000(b)	1	1	2000	12.1	9.8	12.0
2000(b)	1	1	2000	12.4	9.6	12.0
2000(b)	1	10	2000	12.5	9.8	11.0

(a) Cycles between room temperature and exposure temperature.

(b) Exposed in air at 7.6 mm Hg.

(c) Tested in argon at approximately 760 mm Hg.

TABLE 59. SHORT-TIME TENSILE PROPERTIES OF 0.099-GAGE SHEET, 10 PER CENT COLD WORKED, AGED 1100 F FOR 2 HR (Co-20Cr-15W-10Ni)

Strain rate: 0.0001 in./in./sec to yield strength, then 0.01 in./in./sec to rupture.

Reference 34.

Test Temperature, F	Soak, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 in., %	Modulus of Elasticity, 10 ⁶ psi	Hardness, Rockwell C
RT	--	90.0	112.0	154.0	42	30.5	35
1000	15	65.0	82.0	117.5	48	24.1	36
1200	15	56.0	75.2	112.0	47	20.2	36
1400	15	37.0	60.5	97.1	22	18.5	35
1600	15	19.2	34.0	64.4	16	--	36
1800	15	17.2	22.0	45.6	16	9.0	36

TABLE 60. SHORT-TIME TENSILE PROPERTIES OF 0.099-GAGE SHEET, 10 PER CENT COLD WORKED,
AGED 1100 F FOR 2 HR (Co-20Cr-15W-10Ni)

Strain rate: 0.001 in./in./sec to yield strength, then 0.01 in./in./sec to rupture.

Reference 34.

Test Temperature, F	Soak, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 in., %	Modulus of Elasticity, 10 ⁶ psi	Hardness, Rockwell C
RT	--	82.2	116.6	155.9	43	--	36
RT	--	91.5	118.8	157.0	43	31.2	35
800	1	62.0	80.0	117.0	50	23.5	36
800	15	58.0	78.0	122.0	61	26.0	35
1000	1	58.4	78.8	117.5	54	22.8	35
1000	1	60.0	80.0	--	52	22.0	35
1000	15	56.6	76.8	112.7	54	22.4	35
1000	15	50.0	77.0	--	49	21.0	36
1200	1	54.7	76.0	103.5	42	23.5	36
1200	1	48.0	74.0	110.0	51	23.0	35
1200	15	54.4	76.4	109.6	43	--	36
1200	15	57.0	75.0	112.0	47	22.0	35
1400	1	33.0	56.4	91.0	30	17.5	35
1400	1	52.1	63.0	87.5	14	--	35
1400	15	--	--	93.5	39	--	36
1400	15	52.0	64.9	96.9	23	--	36
1600	1	40.2	47.8	62.6	16	--	36
1600	1	37.0	46.0	60.4	8.0	14.0	36
1600	15	43.1	46.9	63.8	14	--	35
1600	15	37.0	49.0	66.8	8.0	16.0	36

TABLE 60. (Continued)

Test Temperature, F	Soak, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Modulus of Elasticity, 10 ⁶ psi	Hardness, Rockwell C
1800	1	22.4	29.2	43.0	12	--	36
1800	1	25.6	27.5	46.4	15	13.2	35
1800	15	17.2	26.5	40.2	12	11.8	36
1800	15	27.3	27.5	42.5	14	12.5	35
2100	1	10.2	10.3	15.9	24	7.7	36
2100	1	10.2	10.4	14.4	20	8.0	35
2100	15	10.1	10.2	16.8	22	8.2	36
2100	15	--	8.6	14.2	19	8.0	35

TABLE 61. SHORT-TIME TENSILE PROPERTIES OF 0.099-GAGE SHEET, 10 PER CENT COLD WORKED,
AGED 1100 F FOR 2 HR (Co-20Cr-15W-10Ni)

Strain rate: 0.01 in./in./sec to yield strength, then 1 in./in./sec to rupture.

Reference 34.

Test Temperature, F	Soak, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Modulus of Elasticity, 10 ⁶ psi	Hardness, Rockwell C
RT	--	96.0	124.0	158.0	32	28.0	36
1000	15	58.0	75.0	130.5	57	24.0	36
1200	15	56.0	69.0	103.0	46	--	36
1400	15	44.5	67.8	100.5	35	21.0	35
1600	15	41.0	51.2	77.3	24	17.4	35
1800	15	34.0	46.8	54.8	20	15.0	36

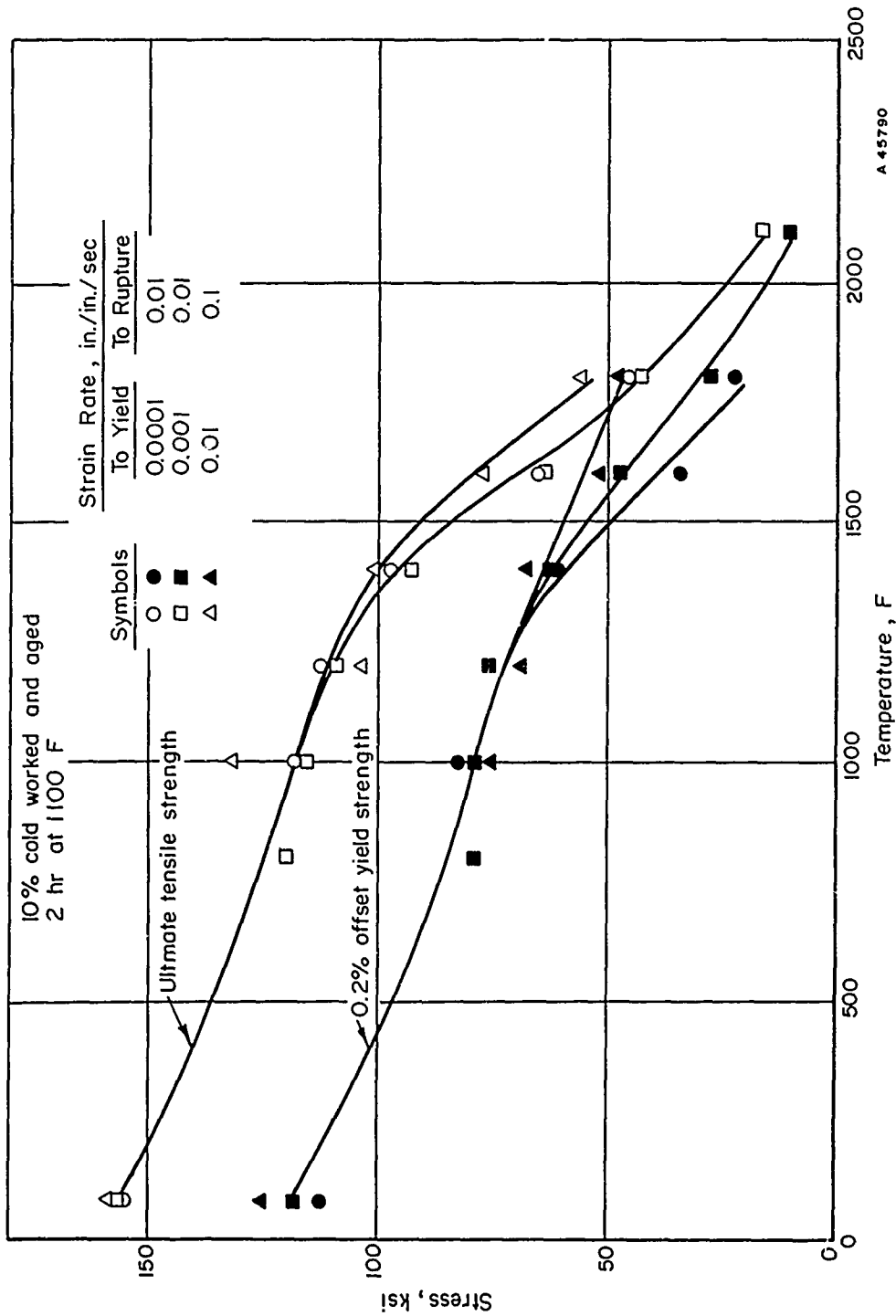


FIGURE 46. SHORT-TIME TENSILE PROPERTIES OF 0.099-IN. SHEET AT VARIOUS STRAIN RATES (Co-20Cr-15W-10Ni)

Reference 34.

TABLE 62. SHORT-TIME TENSILE PROPERTIES OF 0.085-GAGE SHEET, 20 PER CENT COLD WORKED,
AGED 1100 F FOR 2 HR (Co-20Cr-15W-10Ni)

Strain rate: 0.0001 in./in./sec to yield strength, then 0.01 in./in./sec to rupture.

Reference 34.

Test Temperature, F	Soak, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Modulus of Elasticity, 10 ⁶ psi	Hardness, Rockwell C
RT	--	124.0	172.0	193.0	17	29.5	46
1000	15	100.0	128.0	147.0	18	22.5	46
1200	15	89.0	124.0	141.0	8.0	21.0	46
1400	15	43.0	65.5	121.0	8.0	22.0	47
1600	15	34.0	40.5	74.1	8.0	16.0	46
1800	15	16.5	22.5	48.5	12	8.0	46

TABLE 63. SHORT-TIME TENSILE PROPERTIES OF 0.085-GAGE SHEET, 20 PER CENT COLD WORKED, AGED 1100 F FOR 2 HR (Co-20Cr-15W-10Ni)

Strain rate: 0.001 in./in./sec to yield strength, then 0.01 in./in./sec to rupture.

Reference 34.

Test Temperature, F	Soak, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 in., %	Modulus of Elasticity, 10 ⁶ psi	Hardness, Rockwell C
RT	--	123.8	178.0	193.0	13	28.2	46
RT	--	107.0	173.0	191.0	17	31.2	46
800	1	80.0	134.0	160.0	18	27.5	46
800	15	95.0	130.5	152.0	21	28.0	46
1000	1	91.8	126.9	149.5	19	25.6	46
1000	1	76.0	122.0	144.0	18	21.0	46
1000	15	89.4	129.0	152.6	22	23.5	46
1000	15	82.0	122.0	--	21	25.0	46
1200	1	83.3	121.0	137.3	12	--	46
1200	1	84.0	120.0	134.0	8.5	20.0	46
1200	15	79.6	116.6	134.3	12	25.3	47
1200	15	81.0	124.0	143.0	13	24.0	46
1400	1	60.0	91.2	113.3	5.0	22.6	46
1400	1	63.0	89.0	115.0	6.0	16.0	46
1400	15	52.0	91.8	120.0	9.0	16.8	46
1400	15	47.5	90.0	117.5	7.5	22.0	46
1600	1	--	--	73.3	12	--	46
1600	1	44.0	53.5	76.0	7.0	14.5	47
1600	15	--	39.2	70.4	7.0	13.8	46
1600	15	39.0	56.0	77.0	9.0	--	46

TABLE 63. (Continued)

Test Temperature, F	Soak, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Modulus of Elasticity, 10 ⁶ psi	Hardness, Rockwell C
1800	1	31.5	32.0	50.7	7.0	10.3	46
1800	15	29.0	31.5	50.1	11	10.3	46
1800	15	13.9	27.9	44.2	13	13.0	46
2100	1	12.0	9.9	17.3	28	10.4	46
2100	1	9.0	9.8	14.3	19	6.7	46
2100	15	8.2	11.1	15.9	29	8.7	46
2100	15	--	8.5	14.6	23	7.5	46

TABLE 64. SHORT-TIME TENSILE PROPERTIES OF 0.085-GAGE SHEET, 20 PER CENT COLD WORKED, AGED 1100 F FOR 2 HR (Co-20Cr-15W-10Ni)

Strain rate: 0.01 in./in./sec to yield strength, then 0.1 in./in./sec to rupture.

Reference 34.

Test Temperature, F	Soak, min	Proportional Limit, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 in., %	Modulus of Elasticity, 10 ⁶ psi	Hardness, Rockwell C
RT	--	128.0	177.0	194.0	15	34.0	45
1000	15	90.0	124.0	140.0	22	24.5	46
1200	15	84.0	118.0	132.0	15	24.0	46
1400	15	73.0	102.7	119.0	14	20.5	46
1600	15	48.0	76.1	90.4	12	19.5	46
1800	15	31.5	51.3	60.2	11	16.5	46

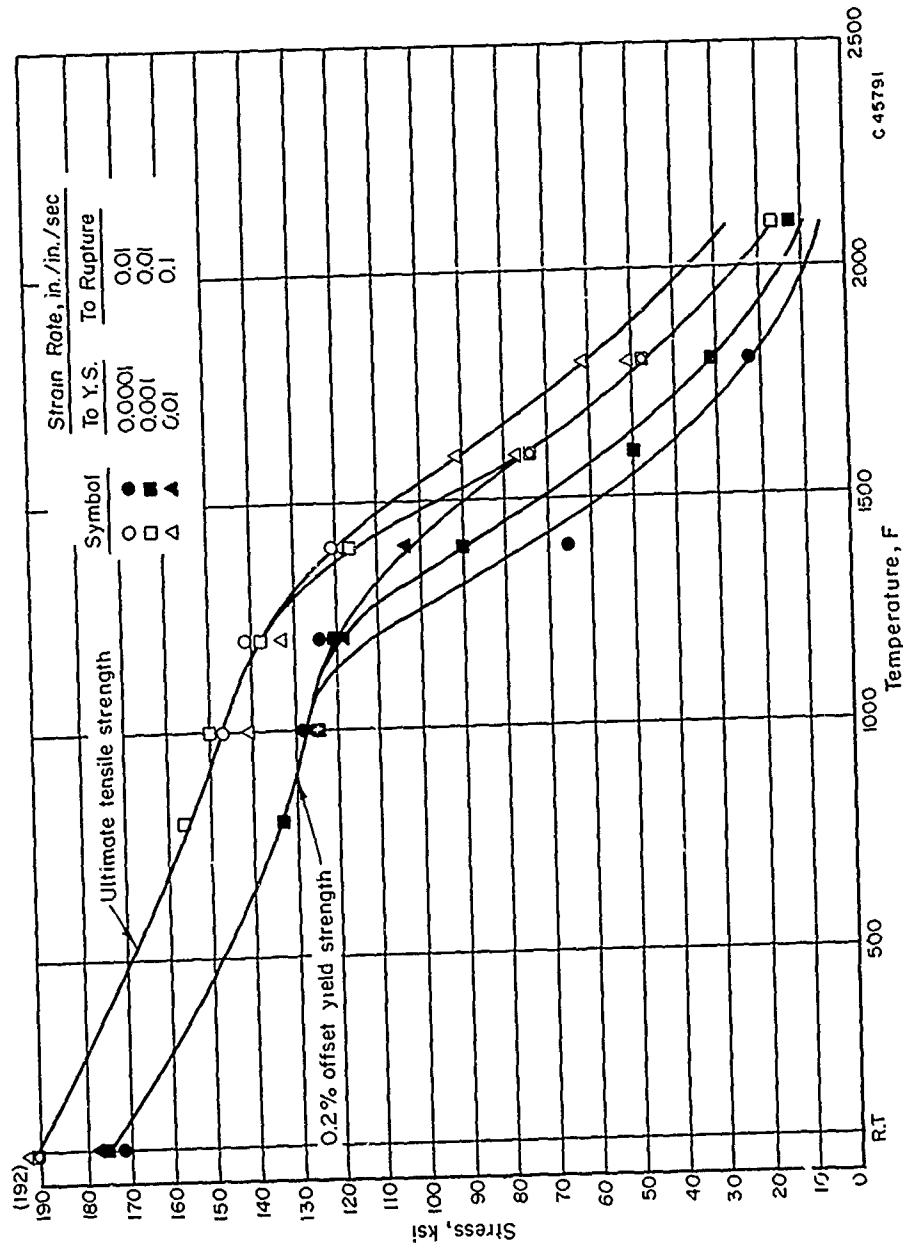


FIGURE 47. SHORT-TIME TENSILE PROPERTIES OF 0.085-IN. SHEET AT VARIOUS STRAIN RATES (Co-20Cr-15W-10Ni)

20% cold worked and aged 2 hr at 1100 F.

Reference 34.

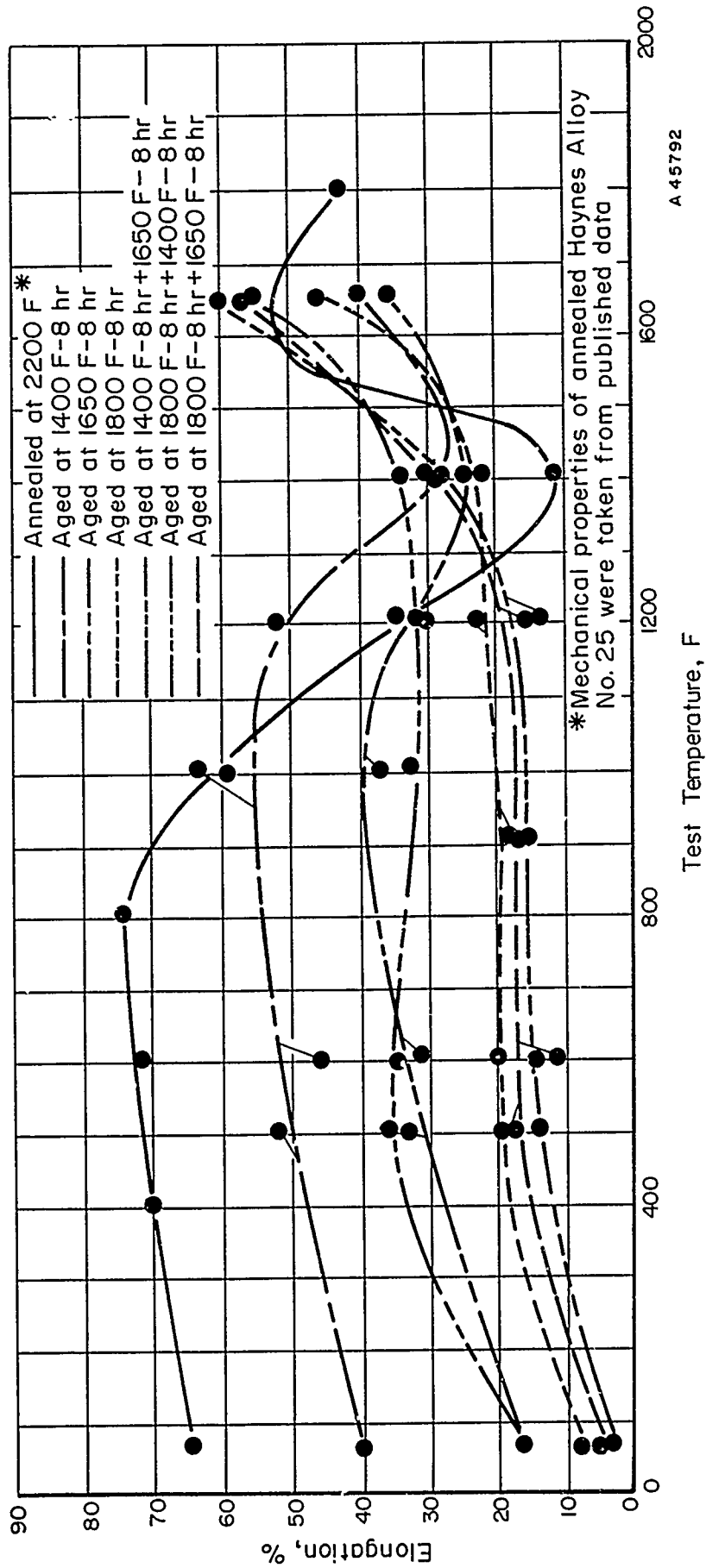


FIGURE 48. EFFECT OF AGING ON HIGH-TEMPERATURE ELONGATION (Co-20Cr-15W-10Ni)

Reference 12.

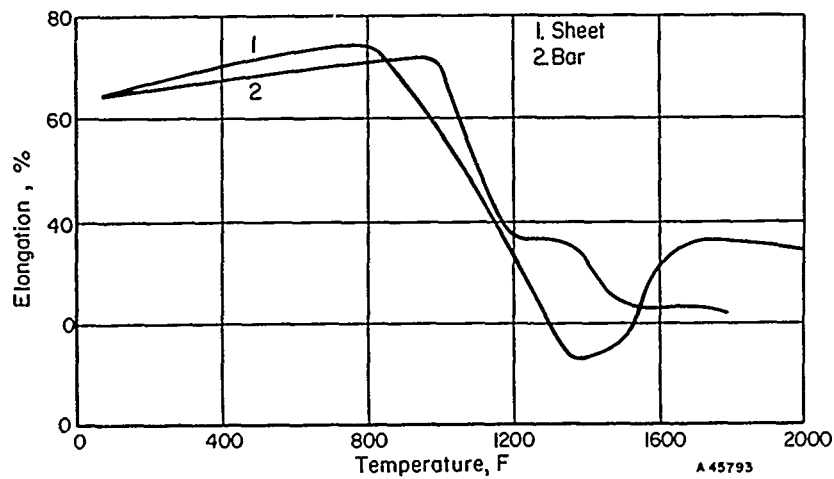


FIGURE 49. TYPICAL ELONGATION VERSUS TEMPERATURE CURVES

Reference 20.

TABLE 65. UNIFORM ELONGATION OF SHEET AT 450 F (Co-20Cr-15W-10Ni)(a)

Reference 10.

Gage, in.	Loading Rate, in. per min	Failing Stress, ksi	Uniform Elongation, %	Total Elongation, %
0.010	25	102.1	45.3	46.7
0.010	25	101.1	44.5	47.1
0.010	25	98.8	37.2	38.3
0.036	4	108.2	43.8	44.9
0.036	4	108.8	49.5	48.6
0.036	4	105.9	39.6	40.8
0.070	4	123.9	55.1	56.6
0.070	4	125.6	62.8	67.6
0.070	4	126.8	56.8	62.1
0.125	4	118.5	67.5	72.9
0.125	4	118.8	75.2	76.3
0.125	4	119.4	60.3	62.8

(a) Twenty-in. specimens, 8-in. gage length.

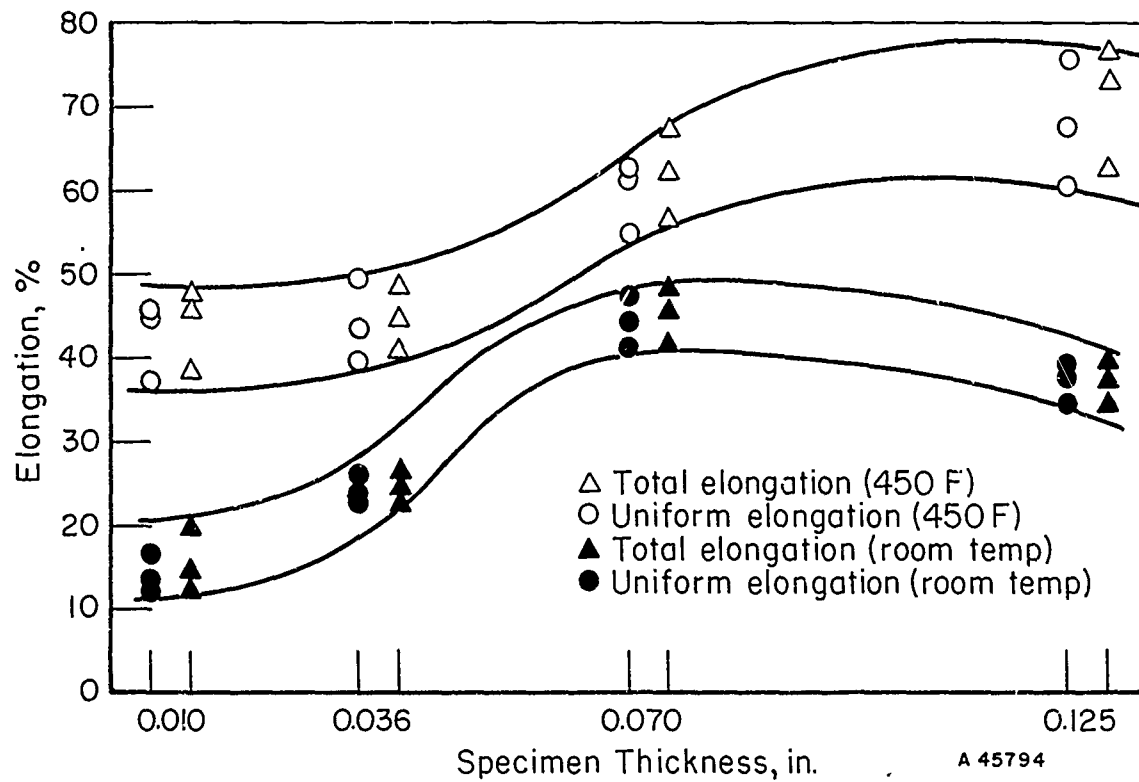


FIGURE 50. UNIFORM ELONGATION VERSUS TOTAL ELONGATION AT ROOM TEMPERATURE AND 450 F (Co-20Cr-15W-10Ni)

Reference 10.

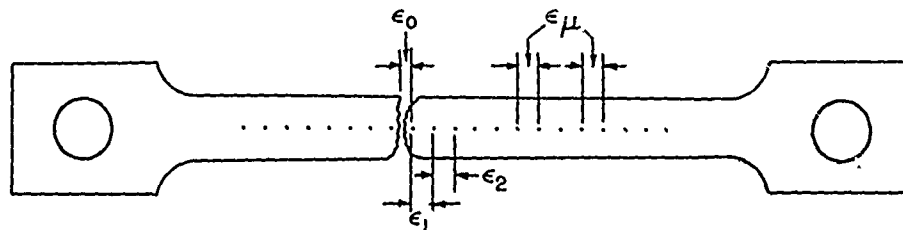
TABLE 66. LONGITUDINAL TENSILE ELONGATION DATA AT STATIC VELOCITY(a)
AND VARIOUS TEMPERATURES (Co-20Cr-15W-10Ni)

Reference 37.

Gage Length, in.	Gage	Temperature, F	ϵ_0 (b)	ϵ_1 (b)	ϵ_2 (b)	ϵ_μ (b)
1	0.020	Room	42	20	18	
1	0.063	Room	88	68	54	
5	0.020	Room	38	25	24	24
5	0.063	Room	41	26	25	24
5	0.125	Room	35	31	21	21
1	0.020	500	84	64	52	
1	0.063	500	87	74	65	
5	0.020	500	82	68	64	54
5	0.063	500	93	70	65	60
5	0.125	500	71	45	47	40
1	0.020	1000	75	69	57	
5	0.020	1000	62	37	35	37
5	0.063	1000	115	60	65	55
5	0.125	1000	58	46	39	38
1	0.020	1500	27	15	14	
5	0.020	1500	86	9	6	5
5	0.063	1500	30	16	16	12
5	0.125	1500	34	15	12	9
5	0.020	-320	26	30	30	27
5	0.125	-320	25	25	25	25

(a) Four in./min head speed.

(b) See sketch for explanation. ϵ_μ = uniform elongation.



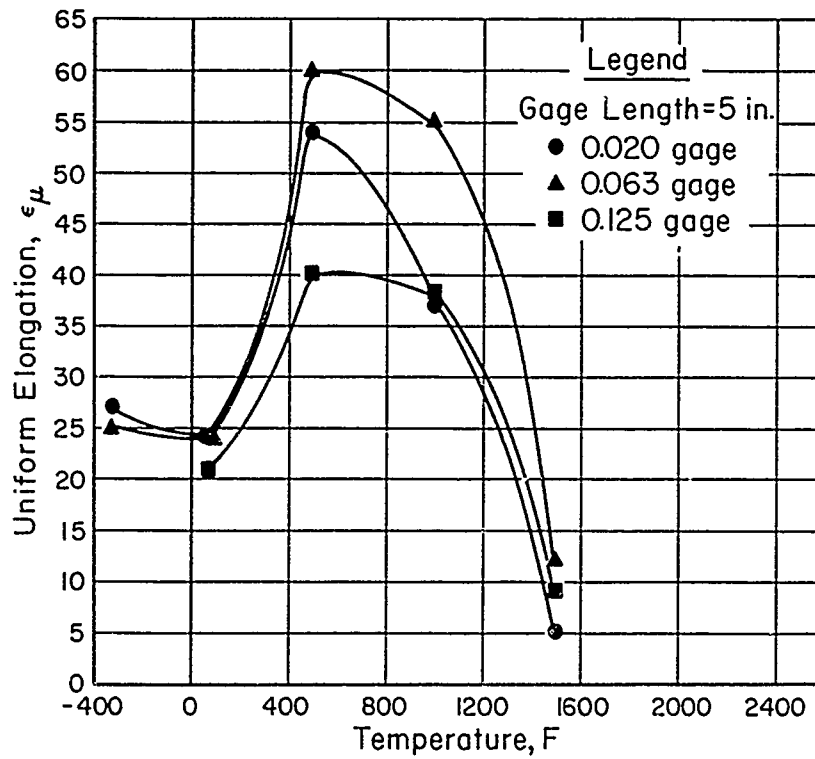


FIGURE 51. VARIATION IN UNIFORM ELONGATION AT FRACTURE FOR VARIOUS TEMPERATURES (STATIC VELOCITY TENSILE TESTS) (Co-20Cr-15W-10Ni)

Reference 37.

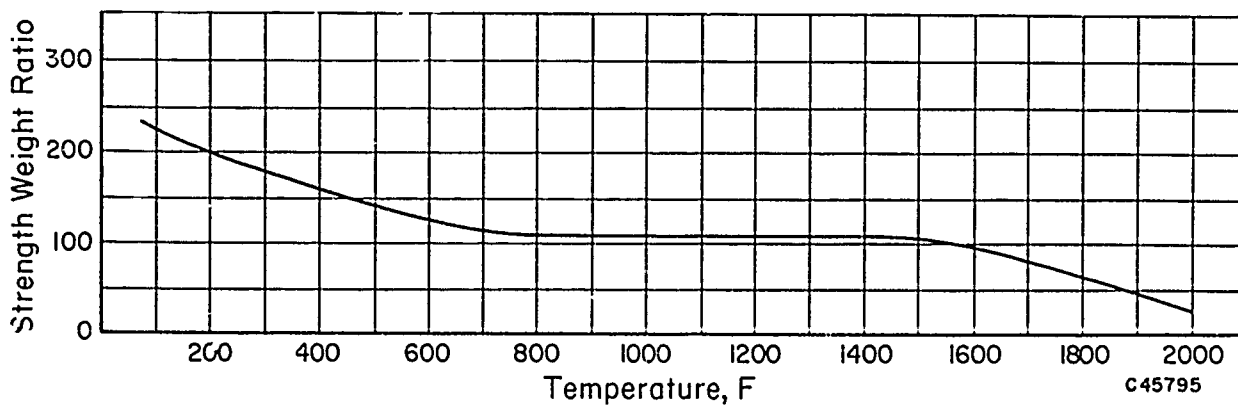


FIGURE 52. EFFECT OF TEMPERATURE ON STRENGTH-WEIGHT RATIO ($\frac{0.2\% \text{ offset yield, Ksi}}{0.333}$) (Co-20Cr-15W-10Ni)

Reference 35.

TABLE 67. REPRESENTATIVE SHORT-TIME ELEVATED-TEMPERATURE TENSILE PROPERTIES (Co-20Cr-15W-10Ni)

0.062-inch sheet, annealed 10 min at 2200 F, and air cooled.

Reference 36.

Test Temperature, F	0.2% Yield Strength, ksi	0.2% Yield Strength/Weight ^(a)	Ultimate Tensile Strength, ksi	Ultimate Tensile Strength/Weight ^(a)
Room	70.0	2.10×10^5	151.0	4.53×10^5
400	64.0	1.92×10^5	147.0	4.41×10^5
600	60.0	1.80×10^5	142.0	4.26×10^5
800	56.0	1.68×10^5	134.0	4.02×10^5
900	54.0	1.62×10^5	128.0	3.84×10^5
1000	52.0	1.56×10^5	121.0	3.63×10^5
1100	49.0	1.47×10^5	110.0	3.30×10^5
1200	47.0	1.41×10^5	97.0	2.91×10^5
1300	44.0	1.32×10^5	81.0	2.43×10^5
1400	41.0	1.23×10^5	68.0	2.04×10^5
1500	37.0	1.11×10^5	54.0	1.62×10^5
1600	34.0	1.02×10^5	44.0	1.32×10^5

(a) Density = 0.333 lb/cu in.

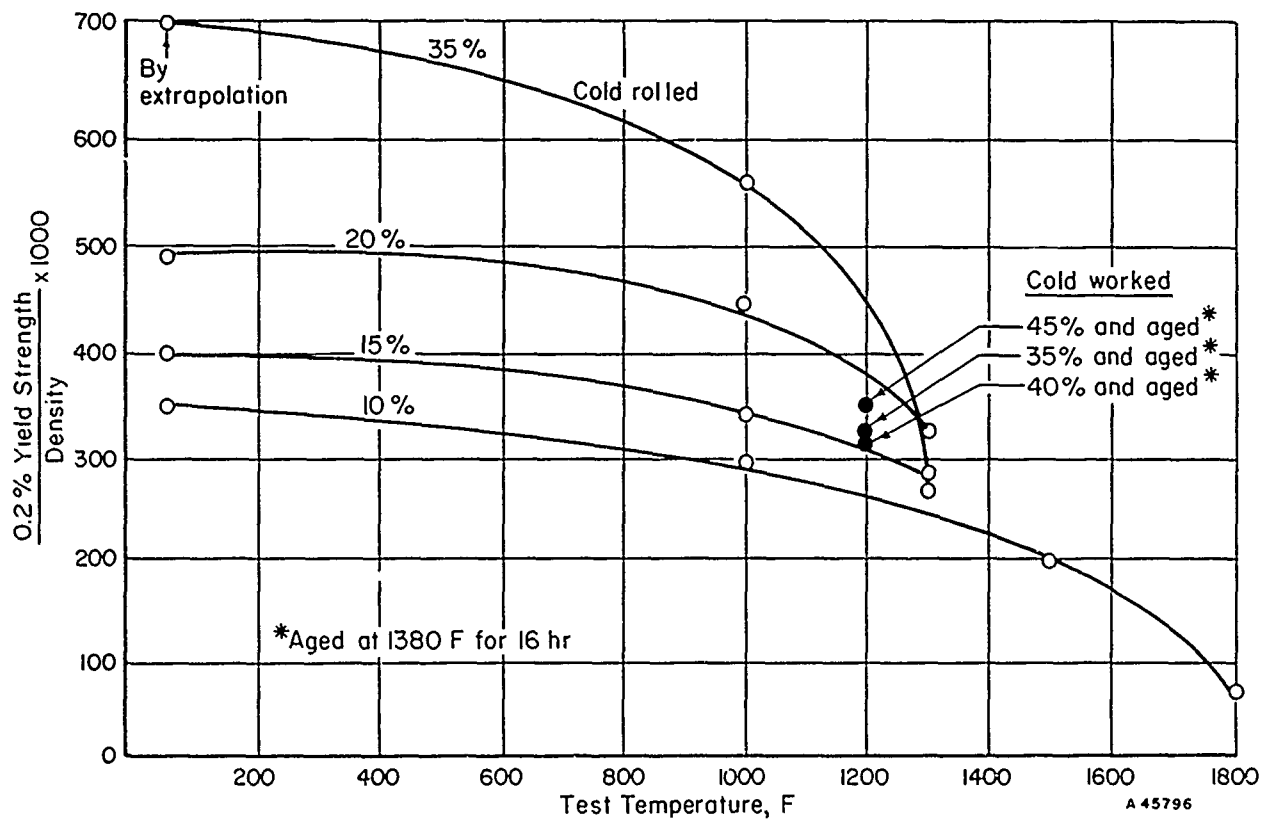


FIGURE 53. 0.2% YIELD STRENGTH DENSITY INDEX OF COLD-ROLLED SHEET TENSILE TESTED AT VARIOUS TEMPERATURES (Co-20Cr-15W-10Ni)

Reference 14.

TABLE 68. MODULUS OF ELASTICITY AT VARIOUS TEMPERATURES (Co-20Cr-15W-10Ni)

Reference 23.

Temperature, F	Modulus of Elasticity, 10^6 psi
70	35.3
1000	28.5
1500	26.8
1800	21.5

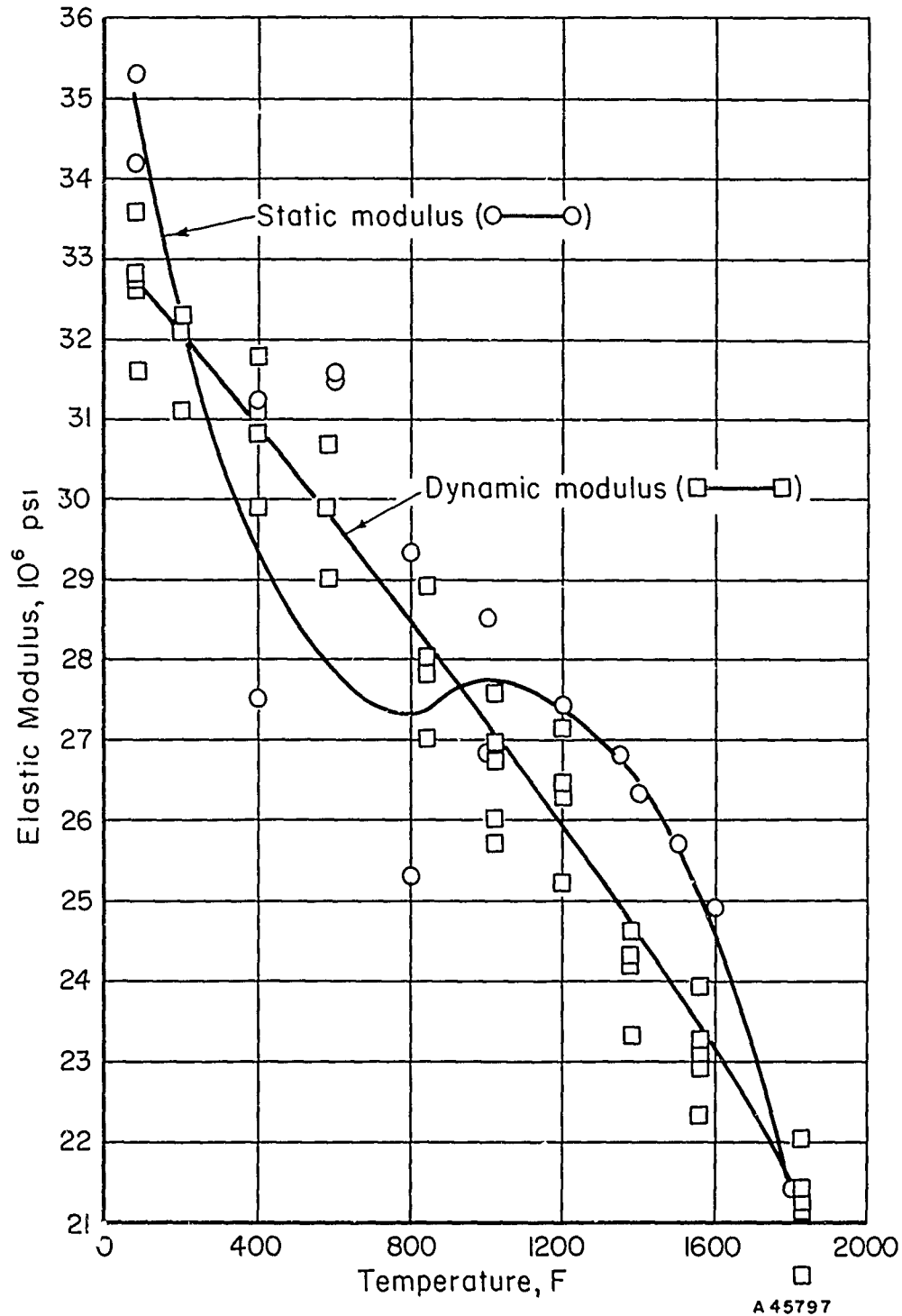


FIGURE 54. EFFECT OF TEMPERATURE ON THE ELASTIC MODULUS
(Co-20Cr-15W-10Ni)

Sheet, heat treated at 2250 F, 20-min, RAC.

Reference 16.

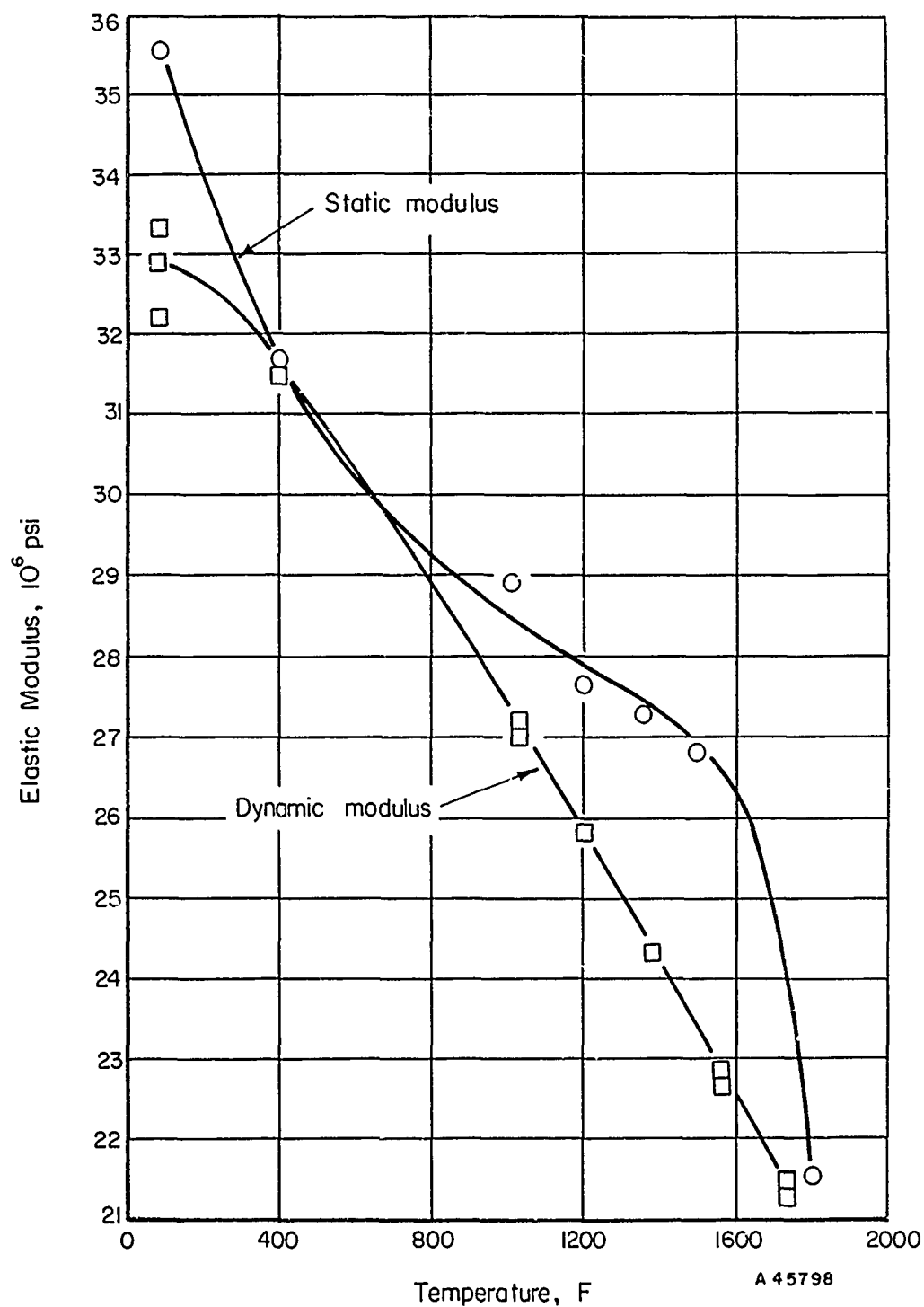


FIGURE 55. EFFECT OF TEMPERATURE ON ELASTIC MODULUS
(Co-20Cr-15W-10Ni)

Bar, heat treated at 2250 F, RAC.

Reference 16.

TABLE 69. DYNAMIC MODULUS OF ELASTICITY (Co-20Cr-15W-10Ni)^(a)

Reference 20.

Form	Condition	Test Temperature, F	Dynamic Modulus of Elasticity, 10 ⁶ psi
Sheet	Heat treated at 2250 F, RAC	77	32.64
Sheet	Ditto	212	32.15
Sheet	"	392	30.98
Sheet	"	572	29.64
Sheet	"	752	28.56
Sheet	"	932	27.32
Sheet	"	1112	26.25
Sheet	"	1292	25.19
Sheet	"	1472	23.71
Sheet	"	1652	22.44
Sheet	"	1832	21.18

^(a) Average of four tests at temperature.

TABLE 70. DYNAMIC MODULUS AT ELEVATED TEMPERATURES (Co-20Cr-15W-10Ni)

Reference 38.

Test Temperature, F	Thickness, d, in. (a)	Width, b, in. (a)	Length, L, in. (a)	Weight, W, grams	Resonant Frequency, F, cps	Young's Modulus, E, 10 ⁶ psi (b)
74	0.0495	0.4807	5.9930	21.2614	283.4	34.1
400	0.0497	0.4818	6.0071		275.1	31.7
800	0.0498	0.4834	6.0268		265.2	29.7
1000	0.0499	0.4843	6.0385		260.2	28.5
1200	0.0500	0.4852	6.0486		254.2	27.1
1400	0.0501	0.4862	6.0614		247.1	25.6
1600	0.0502	0.4874	6.0759		238.6	23.8
1800	0.0503	0.4885	6.0903		227.9	21.7

(a) Dimensional changes due to thermal expansion were calculated.

(b) $E = \frac{5.407 F^2 W L^3}{b d^3} \times 10^{-6}$

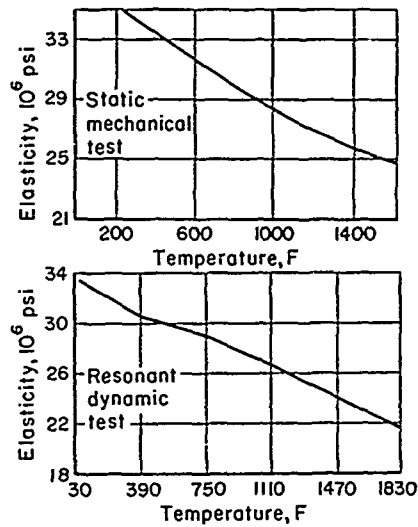


FIGURE 56. MODULUS OF ELASTICITY FOR SHEET AT VARIOUS TEMPERATURES (Co-20Cr-15W-10Ni)

Reference 27, p 249.

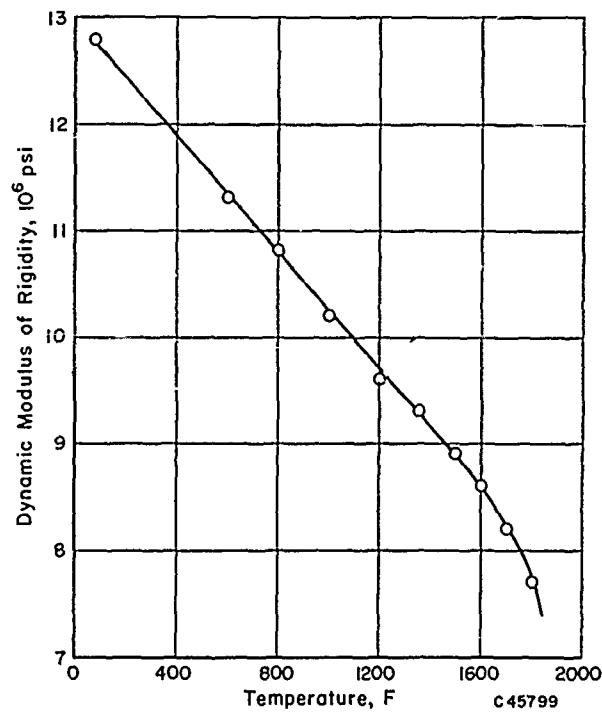


FIGURE 57. DYNAMIC MODULUS OF RIGIDITY VERSUS TEMPERATURE (Co-20Cr-15W-10Ni)

Reference 16.

TABLE 71. SHORT-TIME TENSILE STRENGTH AT VERY HIGH TEMPERATURES (Co-20Cr-15W-10Ni)

Reference 27.

Temperature, F	Ultimate Tensile Strength, ksi	Elongation in 2 In. %
1800	22.3	43
1800	23.9	44
2000	12.8	31
2000	12.9	28
2200	6.8	17
2200	6.8	10
2300	4.6	16
2300	4.6	9.5
2400	3.0	6
2400	3.1	5

TABLE 72. TYPICAL SHORT-TIME TENSILE DATA (Co-20Cr-15W-10Ni)

Bar stock.

Reference 3.

Form	Condition	Test Temperature, F	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation in 1 In., %
Bar, 1-inch diameter	Heat treated at 2225 F, WQ	Room	150.0	70.0	65.0
		1000	109.0	--	71.0
		1200	97.0	--	37.0
		1350	74.1	--	36.0
		1500	65.7	--	24.0
		1650	42.7	--	24.0
		1800	32.9	--	21.0
Bar, 2.75 to 3-inch diameter	Heat treated at 2250 F, WQ	600	117.1	41.3	87(a)

(a) Elongation in 2 in.

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TABLE 73. SHORT-TIME TENSILE TEST RESULTS AT ROOM AND ELEVATED TEMPERATURES ON 0.500-IN. -DIAM BAR-STOCK MATERIAL (Co-20Cr-15W-10Ni)

Reference 25.

Temperature, F	Ultimate Tensile Strength, ksi	Yield Strength, ksi		Elongation, %
		0.2% Offset	0.02% Offset	
R.T	161.3	79.6	64.3	31.0
1000	133.8	47.0	36.0	36.6
1350	108.4	46.2	38.1	26.3
1500	71.8	40.7	31.8	29.3
1650	45.3	37.7	26.2	38.0
1800	27.4	20.3	--	51.0
1900	15.7	14.2	--	44.0

Heat-Treat Condition: 2225 F for 30 min, AC.

Testing Procedure: Standard short-time tensile tests, strain rate 0.005 in./in./min to yield, 0.05 in./in./min yield to fracture.

TABLE 74. ELEVATED-TEMPERATURE TENSILE PROPERTIES OF VACUUM-ARC-MELTED ROUND BAR^(a) (Co-20Cr-15W-10Ni)

Tested at the aging temperature at strain rate of 0.0005 in./in./min.

Reference 39.

Temperature, F	Aging Time, hr	Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, %	Reduction of Area, %
1400	0	32.7	46.6	9	13
1400	0	27.5	56.1	18	25
1400	120	41.3	84.2	24	29
1400	120	30.8	74.4	31	26
1400	350	61.1	92.7	10	20
1400	350	57.3	97.5	18	20
1600	0	25.0	46.8	19	23
1600	0	25.8	55.9	19	22
1600	120	26.7	59.9	38	33
1600	120	39.3	53.9	25	25
1600	350	26.9	56.4	30	36
1600	350	25.5	56.4	37	36
1800	0	14.7	28.8	17	19
1800	0	16.3	35.7	12	26
1800	120	14.7	25.5	22	21
1800	120	20.1	36.0	35	42
1800	350	12.0	33.3	35	43
1800	350	15.5	35.7	32	43
1900	0	9.0	25.1	14	18
1900	0	11.5	23.2	19	19

(a) Analysis: Ni 9.48, Cr 18.2, W 14.2, Fe 0.48, C 0.04, Mn 0.06, Si 0.41, S 0.012, P 0.022, O 0.008, N <0.025.

TABLE 75. ELEVATED-TEMPERATURE TENSILE PROPERTIES OF ROUND BAR SPECIMENS - EFFECT OF SIMULATED BRAZING-CYCLE HEAT TREATMENT (Co-20Cr-15W-10Ni)

Strain rate: 0.0005 in. /in. /min.

Reference 39.

Test Temperature, F	Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, %	Reduction of Area, %
<u>Solution Heat Treated</u>				
RT	66.4	135.4	54	51
400	44.2	112.1	38	38
1000	35.9	103.8	53	37
1600	30.7	54.3	25	33
1800	18.3	33.3	24	45
<u>Solution Heat Treated Plus Special Heat Treatment^(a)</u>				
RT	67.8	131.2	11	11
400	50.5	100.9	9	10
1000	42.8	102.8	20	20
1600	26.9	48.7	51	50
1800	15.1	28.1	52	60

(a) Special heat treatment - 1900 F, 0.25 hr, air cool (2 times) + 1750 F, 1 hr, air cool (simulated brazing and diffusion bonding cycle).

TABLE 76. HOT HARDNESS OF BAR (Co-20Cr-15W-10Ni)

Reference 3.

Test Temperature, F	Hardness at Temperature, Brinell(a)	Recovery Hardness at Room Temperature, Brinell(a)
Room	225	--
752	145	225
932	145	230
1112	130	230
1292	125	232
1472	120	235

(a) Special Brinell hardness tests were made using 2000-kg load and a 10-mm tungsten carbide ball. Both the ball and the specimen were held at temperature for 20 min before testing.

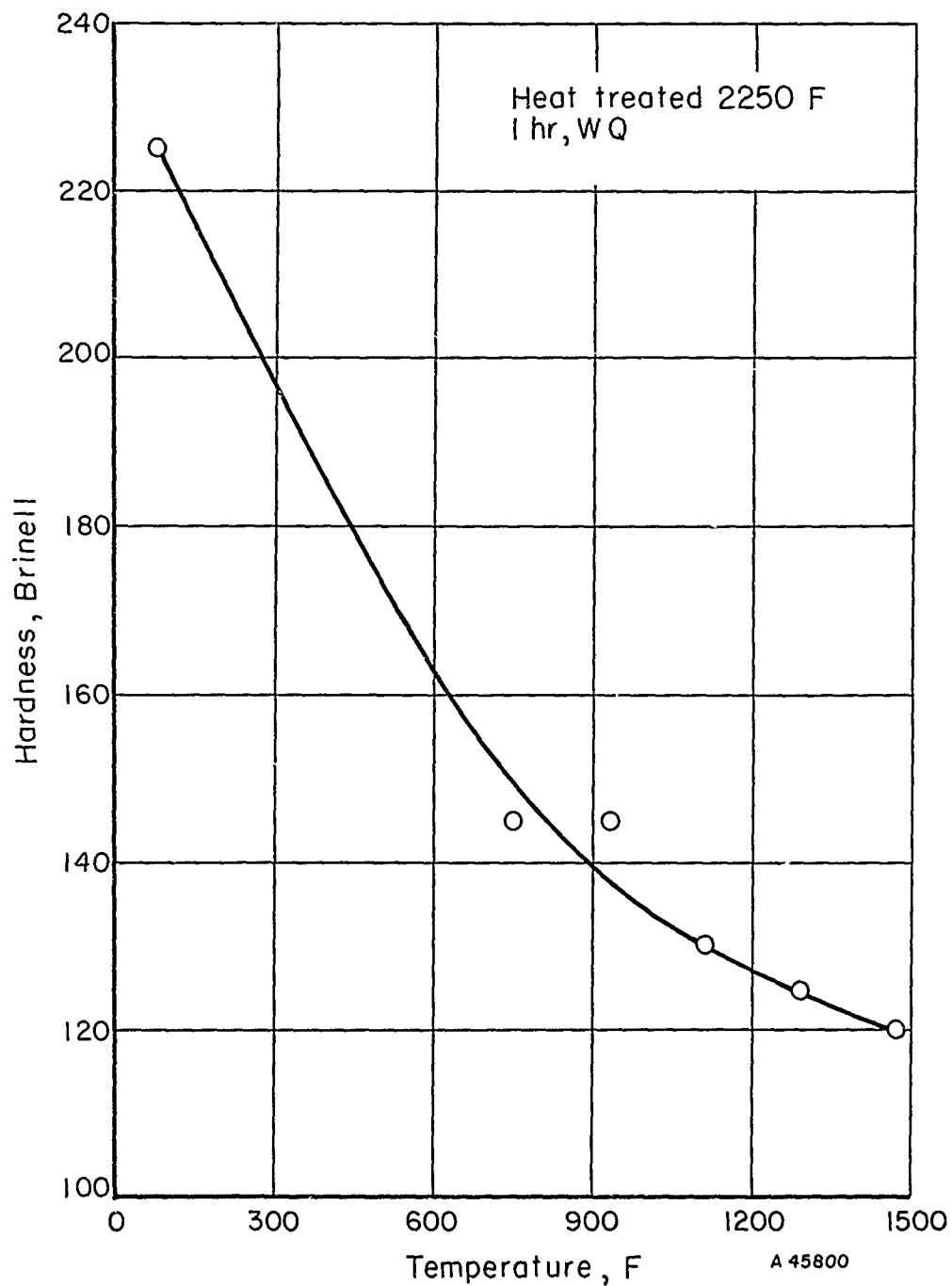


FIGURE 58. EFFECT OF TEMPERATURE ON HARDNESS OF BAR STOCK
(Co-20Cr-15W-10Ni)

Reference 16.

TABLE 77. HOT HARDNESS OF COLD-WORKED AND AGED 0.062-IN. SHEET
(Co-20Cr-15W-10Ni)

Reference 9, Section A.1.

Condition	DPH Hardness ^(a) at Indicated Temperature					Recovered Hardness
	Room Temperature	800 F	1000 F	1200 F	1350 F	
0% CW ^(b)	251	177	161	134	136	257
15% CW	348	254	234	218	200	378
20% CW	401	318	284	268	272	401
25% CW	482	318	300	286	246	482
0% CW + age ^(c)	283	144	142	128	120	269
15% CW + age	390	276	258	240	214	401
20% CW + age	401	214	214	200	185	413
25% CW + age	439	258	272	254	212	453

(a) Sapphire pyramid, 136° point angle; 750-gram load.

(b) CW = cold work.

(c) Age = 1300 F, 10 hr AC.

TABLE 78. HOT HARDNESS OF COLD-WORKED AND AGED SPECIMENS
(Co-20Cr-15W-10Ni)

Reference 9, Section A.11.

Test ^(a) Temperature, F	Hardness, DPH Numbers ^(b)		
	Solution Treated ^(c)	Solution Treated + Cold Work ^(d)	Solution Treated + Cold Work + Age ^(e)
RT	364	482	550
800	236	328	403
1000	--	311	382
1200	215	302	340
1350	209	245	289
RT (after exposure)	435	473	501

(a) Stabilized at each temperature for 1/2 hr before testing.

(b) Load of 750 grams applied for 20 sec on square-based 136° point-angle sapphire pyramid.

(c) Ten min, 2200 F, air cool.

(d) (c) + 36 per cent cold work.

(e) (d) + 5 hr, 950 F.

TABLE 79. SHORT-TIME TENSILE PROPERTIES OF CAST MATERIAL, AFTER VARIOUS HEAT TREATMENTS (Co-20Cr-15W-10Ni)

Reference 9, Section A. 12. 6.

Condition(a)	Test Temperature, F	Ultimate Tensile Strength, ksi	Yield Strength		Elongation, %	Reduction of Area, %
			0.2% Offset, ksi	0.02% Offset, ksi		
S	RT	102.0	60.1	54.1	28.0	29.8
	RT	94.0	59.4	50.7	22.5	35.5
	800	84.4	32.1	26.1	42.0	32.4
	800	76.7	28.3	22.9	42.0	37.5
	1200	79.9	26.8	21.5	27.5	33.3
	1200	68.1	26.3	20.9	32.0	34.5
	1400	47.9	26.3	21.9	(b)	(b)
	1400	44.2	24.6	19.7	24.0	28.7
	1600	43.9	24.6	20.5	25.0	29.8
	1600	42.9	23.4	19.2	26.0	32.7
	1800	28.8	23.3	19.7	(b)	(b)
	1800	26.3	22.7	19.4	23.5	33.7
S, S, A	RT	76.6	60.6	52.5	10.0	15.3
	RT	74.5	59.1	51.1	11.0	20.2
	1200	59.4	26.8	22.4	21.0	26.7
	1200	58.6	26.5	20.7	21.0	32.1
	1600	45.9	25.1	20.4	32.0	32.4
	1600	42.5	23.0	17.5	33.0	33.8
	1800	28.5	22.8	19.7	17.0	31.9
	1800	26.1	22.7	18.5	19.0	36.0

(a) S = solution treatment, 30 min at 2200 to 2250F, SSA = solution treated, stress relieved 2 hr at 2050 F, air cooled, then 30 min at 1650 F, air cooled, then aged for 16 hr at 1350 F.

(b) Bar broke too erratically for per cent elongation and per cent RA determinations.

TENSILE PROPERTIES OF WELDED AND BRAZED JOINTS

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TABLE 80. TYPICAL SHORT-TIME TENSILE DATA, WELDMENTS^(a)
(Co-20Cr-15W-10Ni)

Reference 3.

Weld Method and Material	Test Temperature, F	Ultimate Tensile Strength, ksi	0.2 % Offset, Yield Strength ksi	Elongation in 2 In., %
<u>Metallic Arc</u>				
Sheet, 0.094 in.	Room	130.2	73.2	29.7
	1500	65.6	35.8	16.3
Sheet, 0.125 in.	Room	133.4	70.5	34.6
	1500	64.6	33.7	15.1
Plate, 0.250 in.	Room	132.4	72.2	33.3
	1500	72.4	34.4	21.4
<u>Inert-Gas-Shielded Arc</u>				
Sheet, 0.094 in.	Room	135.6	74.2	37.8
	1500	68.5	36.1	19.0
Sheet, 0.125 in.	Room	137.1	72.0	40.1
	1500	69.2	33.6	22.9
Plate, 0.250 in.	Room	136.3	72.5	42.2
	1500	70.9	35.0	24.2

(a) All material solution heat treated prior to welding and tested in the as-welded condition.

TABLE 81. SHORT-TIME TENSILE RESULTS AT ROOM AND ELEVATED TEMPERATURE ON WELDED SHEET MATERIAL^(a)
(Co-20Cr-15W-10Ni)

Reference 25.

Temperature, F	Ultimate Tensile Strength, ksi ^(b)	0.2 % Yield Strength, ksi	0.02 % Yield Strength, ksi	Elongation, %	Fracture
RT	139.0	58.3	51.5	58.5	Weld
RT	137.7	66.8	53.7	55.0	Weld
1000	101.0	36.0	32.8	50.5	Weld
1000	96.7	36.2	32.7	-	Pin Hole
1200	87.7	37.8	33.4	25.0	Weld
1200	89.7	37.8	32.2	-	Pin Hole
1350	76.5	32.5	26.6	18.5	Weld
1350	84.5	33.8	26.5	22.0	Weld
1500	60.7	31.9	24.1	23.0	Weld
1500	60.4	29.9	25.2	22.0	Weld
1650	34.9	31.9	30.0	30.0	P.M.
1650	34.6	32.6	27.8	30.0	Weld
1800	22.9	20.9	15.5	17.0	Weld
1800	26.2	22.0	17.3	22.0	Weld
1900	17.2	9.9	9.4	15.0	Weld
1900	18.6	9.5	8.5	14.0	Weld
2000	9.9	7.9	7.2	14.0	Weld
2000	9.1	8.0	7.3	15.5	P.M.
2100	8.2		4.3	6.5	Weld
2100	6.0	4.6	3.6	7.0	Weld

(a) 0.062-inch sheet material. Inert-arc-welding process using argon, and filler material from the base stock. Heat treated 2225 F for 30 min and air cooled after welding.

(b) Strain rate 0.005 in./in./min to the yield, and 0.05 in./in./min to fracture.

TABLE 82. ROOM- AND ELEVATED-TEMPERATURE TENSILE PROPERTIES
(Co-20Cr-15W-10Ni)

Base metal and fusion butt-welded test specimens. (a)

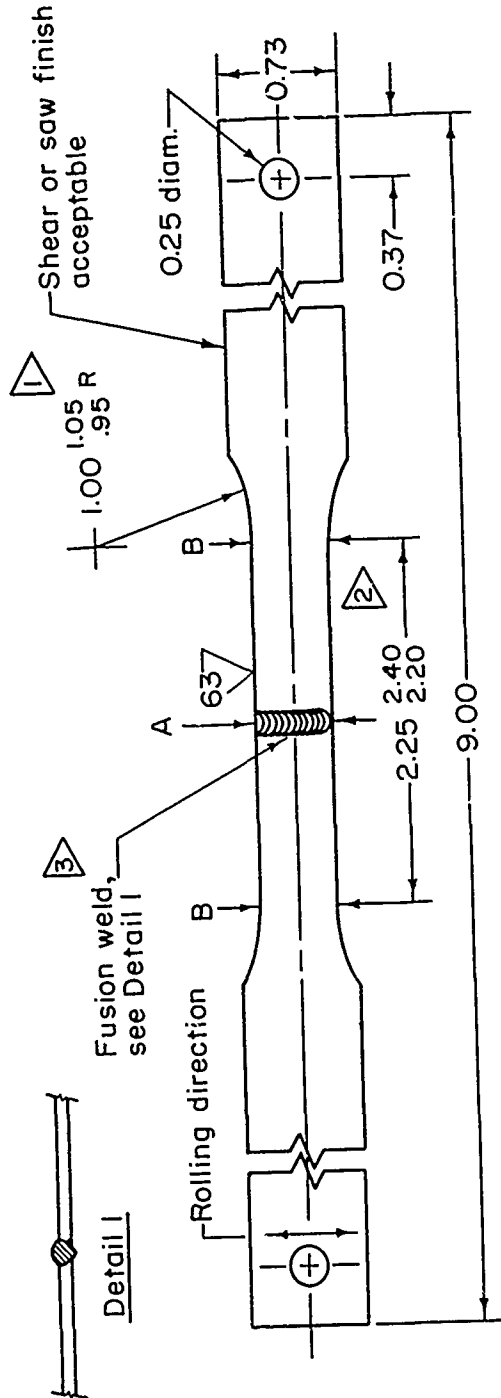
Reference 6.

Gage, in.	Specimen Type	Test Temperature, F	Ultimate Tensile Strength, ksi ^(b)	0.2 % Yield Strength, ksi	Elongation, % in		
					1/2 In.	1 In.	2 In.
0.010	BM ^(c)	70	114.6	75.9	22.0	19.0	17.3
0.010	Welded	70	125.5	70.3	21.2	20.0	18.8
0.010	BM	70	116.4	59.3			27.5
0.010	Welded	70	115.7	63.0	25.2	22.6	23.8
0.010	BM	1600	33.2	32.3	17.6	13.3	7.3
0.010	Welded	1600	30.8	25.7	12.0	10.2	5.8
0.010	BM	2000	10.1	9.7	11.6	9.6	6.0
0.010	Welded	2000	8.7	8.4	7.5	6.4	3.6
0.040	BM	70	100.1	75.1	11.3	10.0	8.6
0.040	Welded	70	114.1	73.3	21.2	18.2	16.6
0.040	BM	1600	37.7	35.1	17.6	13.3	8.6
0.040	Welded	1600	35.5	34.4	12.8	9.6	6.0
0.040	BM	2000	11.6	10.6	14.6	10.6	7.0
0.040	Welded	2000	11.6	10.9	15.6	12.4	7.0

(a) See Figures 62 and 63, for design of specimens.

(b) All values are averages of three base metal and five welded specimens. Strain rate 0.005 in./in./min.

(c) BM = base metal.

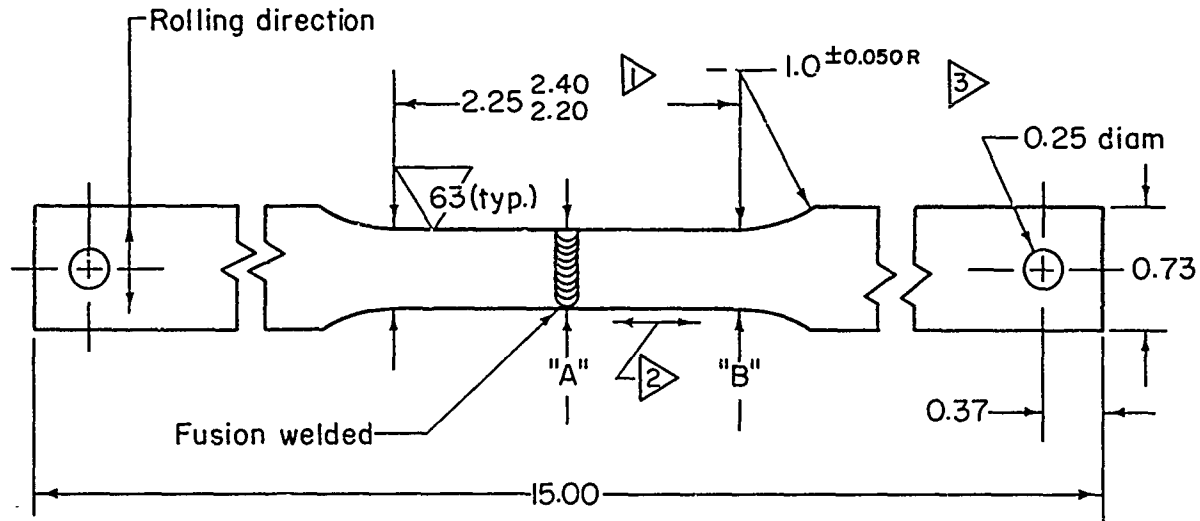


- 1 Fillet radii must fair smoothly into the reduced section.
- 2 The reduced section must be symmetrical about the ϕ of the holes to within ± 0.01 . The "B" width must decrease uniformly and smoothly into the "A" width at the center.
- 3 Do not remove weld bead.
- A 45801
- All dimensions are in inches.

A	0.505 max. 0.495 min.
B	A + 0.003 to A + 0.005

FIGURE 59. FUSION-WELDED SPECIMEN FOR ROOM-TEMPERATURE TENSILE TEST

Reference 6.



Notes:

"A"	Max.	0.505
	Min.	0.495
"B"	Max.	"A" + 0.005
	Min.	"A" + 0.003

- 1 Reduced section must be symmetrical about longitudinal \bar{C} within 0.010 and decrease uniformly and smoothly to "A" dimension.
 - 2 Finish-grind direction parallel to specimen edge.
 - 3 Fillet radii must fair smoothly with "B" dimension.
- All dimensions are in inches. A 45802

FIGURE 60. FUSION-WELDED SPECIMEN FOR ELEVATED-TEMPERATURE TESTS

Reference 6.

TABLE 83. ROOM-TEMPERATURE TENSILE PROPERTIES FOR THERMALLY CYCLED BASE METAL AND FUSION BUTT-WELDED SPECIMENS^(a)
(Co-20Cr-15W-10Ni)

Reference 6.

Number of Cycles	Cycle Temperature ^(b) , F	Specimen Type	Condi- tion ^(c)	Ultimate Tensile Strength, ksi ^(d)	Yield Strength, ksi	Elongation, % in		
						1/2 In.	1 In.	2 In.
0		BM ^(e)	S-T	116.4	59.3			27.5
0		Welded	S-W-T	115.6	63.0	25.2	22.6	23.8
1	1800	BM	S-T	125.6	62.8			31.8
1	1800	Welded	S-W-T	124.4	59.3	34.4	32.2	31.8
3	1800	BM	S-T	121.7	62.9			27.6
3	1800	Welded	S-W-T	124.2	60.6	34.0	32.2	30.4
5	1800	BM	S-T	119.6	62.7			26.3
5	1800	Welded	S-W-T	125.4	61.0	31.2	29.2	28.0
10	1800	BM	S-T	117.6	62.0			24.0
10	1800	Welded	S-W-T	118.5	59.6	24.8	22.6	21.4
10	2000	BM	S-T	118.4	61.1			23.3
10	2000	Welded	S-W-T	117.5	57.0	24.8	25.2	23.8

(a) All values are averages of three base metal and five welded specimens, 0.010-gage sheet.

(b) Cycle: heat to exposure temperature in air, hold for 10 min, then air cool to room temperature.

(c) S = solution heat treat (as received);

W = weld;

T = test.

(d) Strain rate 0.005 in./in./min.

(e) Base metal.

TABLE 84. EFFECT OF AGING ON ROOM-TEMPERATURE TENSILE PROPERTIES OF HELIARC-WELDED SHEET (Co-20Cr-15W-10Ni)

0.160-in. sheet, weld metal bead perpendicular to the specimen axis - excess metal removed by grinding.

Reference 9, Section A.6.

Aging Conditions	Ultimate Tensile Strength, ksi	0.02 % Offset Yield Strength, ksi	0.2 % Offset Yield Strength, ksi	Elonga- tion, %
1000 hr at 1600 F	140.0	58.3	85.5	3
100 hr at 1850 F + 1000 hr at 1600 F	115.5	73.5	87.8	1.5
1000 hr at 1600 F cycled to 1850 F 2 hr out of every 24 hr	139.0	68.0	79.8	7

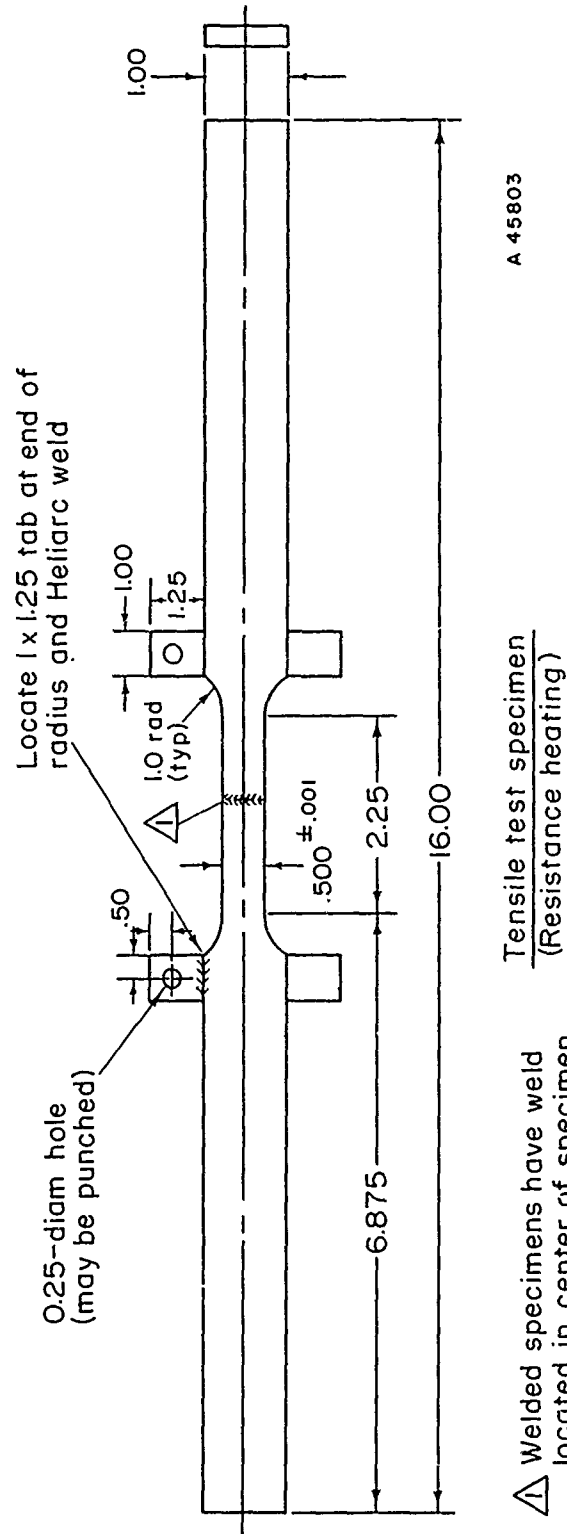
TABLE 85. AVERAGE TENSILE PROPERTIES AT ELEVATED TEMPERATURES
OF 0.050-IN. SHEET WELDED AND UNWELDED^(a)
(Co-20Cr-15W-10Ni)

Reference 38.

Type	Test Temperature ^(b) , F	Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, %
Unwelded	RT	76.5	141.5	42
Welded		75.5	133.0	31
Unwelded	400	57.0	118.0	37
Welded		51.0	119.0	46
Unwelded	800	43.0	109.0	48
Welded		43.0	103.0	42
Unwelded	1000	40.5	101.0	42
Welded		42.0	96.0	42
Unwelded	1200	38.5	91.0	39
Welded		39.5	87.0	35
Unwelded	1400	35.5	71.5	23
Welded		39.0	66.0	19
Unwelded	1600	33.5	59.0	28
Welded		34.0	57.0	21
Unwelded	1800	32.5	33.5	19
Welded		33.5	34.5	19
Unwelded	2000	18.5	19.0	17
Welded		17.0	18.0	12
Unwelded	2200	8.7	9.1	19
Welded		7.8	8.7	15

(a) Three welded and three unwelded specimens tested at each temperature. See Figure 61 for design of welded test specimen.

(b) Resistance heated 100 F per sec, held at test temperature for 3 min; tested at 0.0002 in./in./sec.



Tensile data in Table 85

FIGURE 61. DESIGN OF TEST SPECIMENS

Reference 38.

TABLE 86. EFFECT OF BRAZING AND THERMAL EXPOSURE ON THE SHORT-TIME TENSILE PROPERTIES OF 0.0045-IN. FOIL (a) (Co-20Cr-15W-10Ni)

Reference 40.

Exposure in Air, F	Test Temperature, F	Unbraze			Braze (b)			Remarks
		Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elonga- tion in 2 In., %	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elonga- tion in 2 In., %	
None 5 hr at 2000 1 hr at 2200	RT	109.6	71.3	14	114.8	64.5	21	Failure in braze
	RT	123.6	62.2	21	73.7	45.0	5	Failure outside braze
	RT	61.4	47.9	4.5	74.4	59.8	4	Failure at edge of braze
None 5 hr at 2000 1 hr at 2200	1600	42.3	33.7	10	44.1	30.8	6	Failure outside braze
	1600	36.5	36.2	1	22.2	-	0.5	Failure at edge of braze
	1600	21.4	-	1	16.5	-	0	Failure at edge of braze
None 5 hr at 2000 1 hr at 2200	1800	28.1	25.0	7	30.4	26.0	12	Failure at edge of braze
	1800	22.5	21.5	2	16.6	16.5	2.5	Failure in braze
	1800	14.1	13.8	1	10.3	10.2	2	Failure outside braze
None 5 hr at 2000 1 hr at 2200	2000	13.6	13.0	9	14.5	12.2	13	Failure in braze
	2000	13.3	10.7	2.5	9.1	8.2	3.5	Failure at edge of braze
	2000	6.6	6.6	1	2.7	2.7	1	Failure outside braze
None 5 hr at 2000 1 hr at 2200	2200	7.0	5.2	7	5.6	4.6	5	Failure at edge of braze
	2200	6.5	5.2	4	5.2	4.1	3	Failure at edge of braze
	2200	2.9	2.8	3.5	1.2	-	0	Failure outside braze

(a) Bell Aerosystems Program.

(b) GE J8100 braze alloy applied on one side for a distance of 1 in. in the center of the gage section (see Figure 62).

TABLE 87. EFFECT OF BRAZING AND THERMAL EXPOSURE ON THE SHORT-TIME TENSILE PROPERTIES OF 0.0045-IN. FOIL^(a) (Co-20Cr-15W-10Ni)

Reference 40.

Exposure in Air, F	Test Temperature, F	Unbraze			Braze ^(b)			Remarks
		Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elonga- tion in 2 In., %	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elonga- tion in 2 In., %	
None	RT	138.6	81.0	20	103.8	77.9	3	Failed in base metal
5 hr at 2000	RT	123.4	54.6	28	74.5	52.1	4	Failed in base metal
1 hr at 2200	RT	69.3	49.8	19	102.6	59.8	8	Failed in base metal
None	1600	46.6	37.6	11	46.4	31.6	8.5	Broke outside gage
5 hr at 2000	1600	39.1	37.9	3	32.4	31.7	3	Failed in base metal
1 hr at 2200	1600	6.7	-	0	27.2	27.0	2	Failed at edge of braze area
None	1800	27.8	20.5	10	27.4	19.3	12	Failed at edge of braze area
5 hr at 2000	1800	21.3	21.1	2.5	19.4	18.0	2	Failed in base metal
1 hr at 2200	1800	17.6	17.6	4	16.3	16.3	1	Failed in braze area
None	2000	12.6	10.0	10	14.6	10.0	11	Failed in base metal
5 hr at 2000	2000	11.7	11.3	5	11.2	9.4	5	Failed at edge of braze area
1 hr at 2200	2000	5.6	5.6	1	7.3	6.9	3	Failed in braze area
None	2200	5.2	3.5	6	6.9	3.0	10	Failed at edge of braze area
5 hr at 2000	2200	4.0	2.9	2	2.6	2.6	2	Failed in braze area
1 hr at 2200	2200	0.6	-	1	1.7	1.7	2	Failed at edge of braze area

(a) Norair program.

(b) Microbraze 30 applied on one side for a distance of 1 in. in the center of the gage section (see Figure 62).

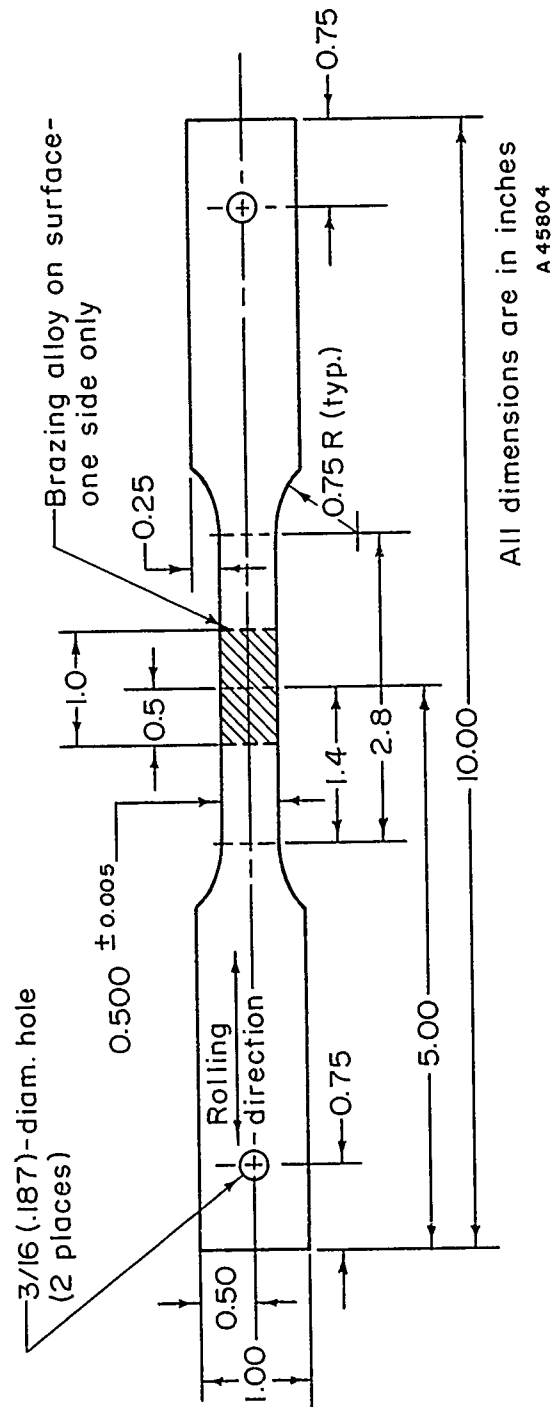


FIGURE 62. BRAZED COATED TENSILE TEST SPECIMEN

Reference 40.

TENSILE PROPERTIES AT CRYOGENIC TEMPERATURES

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TABLE 88. TENSILE PROPERTIES AT LOW TEMPERATURES
(Co-20Cr-15W-10Ni)

Plate, heat treated at 2225 F and water quenched.

Reference 3.

Test Temperature, F	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Elastic Modulus, 10 ⁶ psi
-321	207.2	37.0	35.7
-108	171.2	50.0	--
75	140.7	58.0	35.0

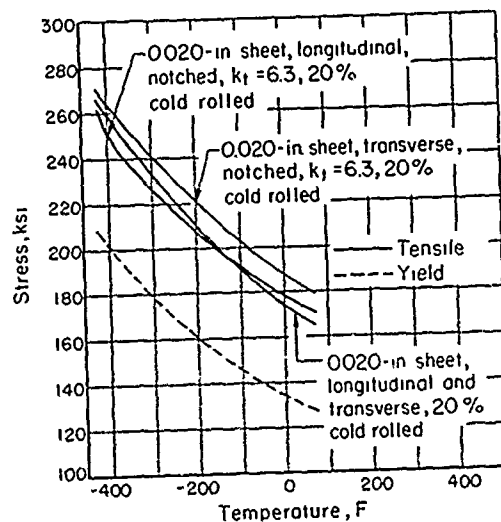


FIGURE 63. TENSILE PROPERTIES OF SHEET AT CRYOGENIC TEMPERATURES (Co-20Cr-15W-10Ni)

Reference 41.

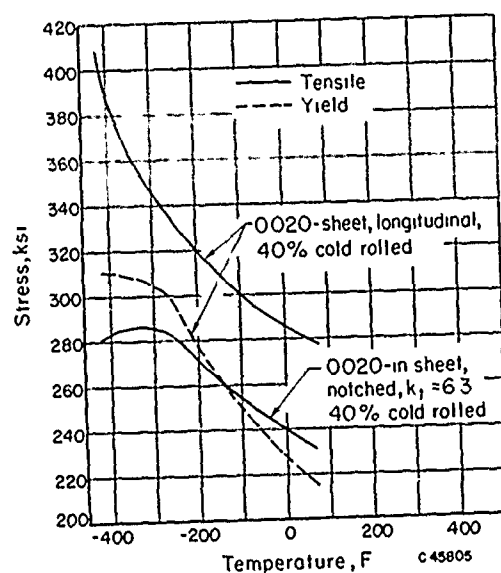


FIGURE 64. TENSILE PROPERTIES OF COLD-ROLLED SHEET AT CRYOGENIC TEMPERATURES (Co-20Cr-15W-10Ni)

Reference 41.

TABLE 89. STRENGTH/DENSITY AND NOTCHED/UNNOTCHED TENSILE RATIOS FOR SHEET AT CRYOGENIC TEMPERATURES (Co-20Cr-15W-10Ni)

Calculations based on longitudinal data.

Reference 42.

Condition	Test Temperature, F	Yield Strength/ Density ^(b) , in.	Tensile Strength/ Density ^(b) , in.	Notched/ Unnotched Tensile Ratio (K _t = 6.3)	Gage, in.
20 % cold rolled	+78	0.38×10^6	0.50×10^6	1.03	0.020
	-100	0.44×10^6	0.58×10^6	1.00	
	-320	0.55×10^6	0.77×10^6	0.91	
	-423	0.63×10^6	0.81×10^6	0.98	
40 % cold rolled	+78	0.65×10^6	0.84×10^6	0.83	0.008
	-320	0.93×10^6	1.07×10^6	0.82	
	-423	0.94×10^6	1.24×10^6	0.69	

(a) Yield and tensile strengths in psi; density in lb/in.³.

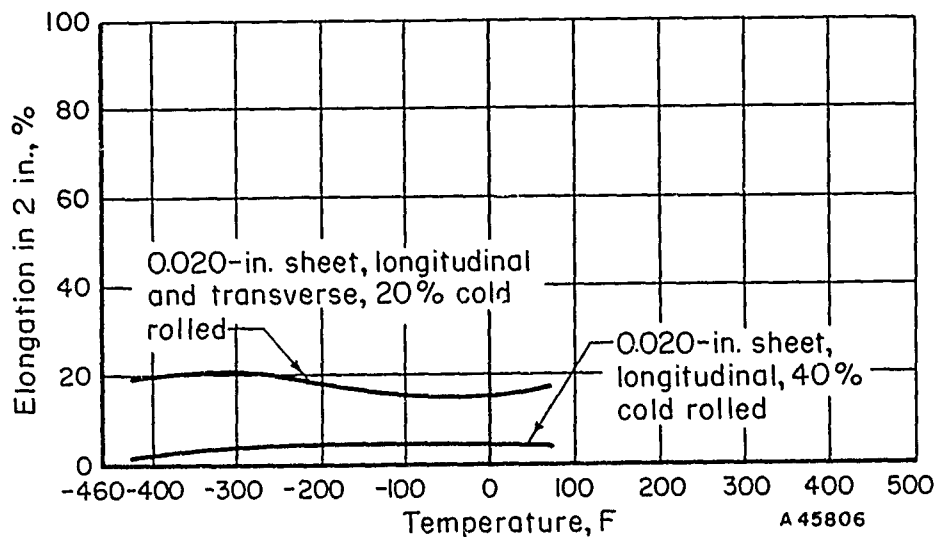


FIGURE 65. ELONGATION OF COLD-ROLLED SHEET AT CRYOGENIC TEMPERATURES (Co-20Cr-15W-10Ni)

Reference 41.

TABLE 90. EFFECT OF CRYOGENIC TEMPERATURES ON THE MECHANICAL PROPERTIES
(Co-20Cr-15W-10Ni)

Reference 43.

Test Temperature, F	Direction	0.2 % Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, %	20 % Cold Rolled(c)			40 % Cold Rolled(d)			Heliarc Butt Weld		Weld Elongation, %
											Notched Ultimate Tensile Strength(a), ksi	Notched/Unnotched Tensile Ratio	
78	Longitudinal	126	164	16	170	1.03	131	2					
	Transverse	127	165	17	178	1.08							
	Longitudinal	146	192	16	191	1.00							
-100	Longitudinal	146	189	15	204	1.08							
	Transverse	181	255	23	231	0.91	178	2					
-320	Longitudinal	182	238	19	245	1.03							
	Transverse	208	268	20	262	0.98	206	2					
-423	Longitudinal	210	265	18	272	1.02							
-423	Transverse												
78	Longitudinal	215	278	3	231	0.83	203	1					
	Longitudinal	307	352	3	287	0.82	233	1					
	Longitudinal	311	408	1	281	0.69	243	0					

(a) Stress-concentration factor $K_t = \sqrt{\frac{1/2 \text{ width between notches}}{\text{radius of the notch}}} = 6.3$.

(b) Heliarc butt weld: roll planished; no doubler reinforcement.

(c) Sheet 0.020 inch thick; data are the average of three and two tests in the longitudinal and transverse directions, respectively.

(d) Sheet 0.008 inch thick; data are the average of three tests.

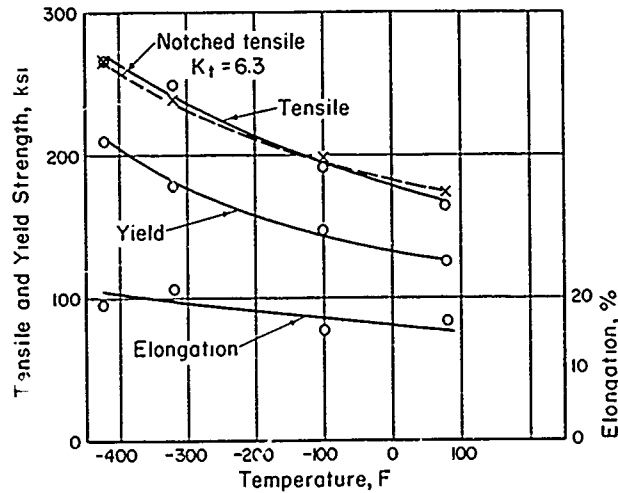


FIGURE 66. TENSILE PROPERTIES AT CRYOGENIC TEMPERATURES (Co-20Cr-15W-10Ni)

Sheet, 20% cold rolled, 0.020 inch thick; average of longitudinal and transverse tests.

Reference 42.

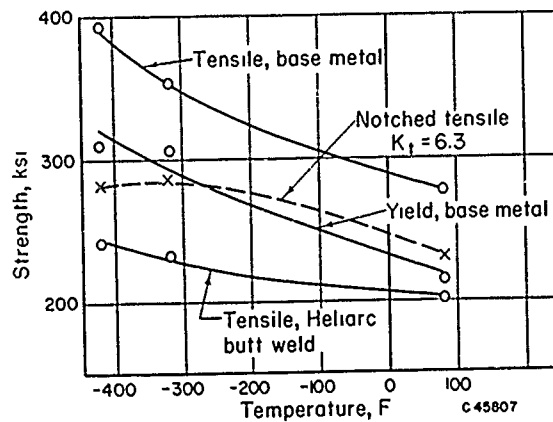


FIGURE 67. TENSILE PROPERTIES AT CRYOGENIC TEMPERATURES FOR SHEET AND HELIARC-BUTT-WELDED SHEET (Co-20Cr-15W-10Ni)

Sheet, 40% cold rolled, 0.008 inch thick, longitudinal tests.

Reference 42.

TABLE 91. SHORT-TIME TENSILE PROPERTIES AT CRYOGENIC AND ELEVATED TEMPERATURE (Co-20Cr-15W-10Ni)

0.010-in. sheet, cold rolled 10 per cent, not annealed.
Reference 44.

Test Temperature, F	Grain Direction	0.2 % Offset Yield Strength, ksi	Tensile Strength, ksi	Elongation, %	Notched Tensile Strength $K_t = 6.3$, ksi	Notched/ Unnotched Ratio
-423	L	166.7	188.4	2.5	211.6	1.12
-423	T	173.5	198.9	2.7	211.8	1.06
-320	L	146.8	170.6	2.9	182.4	1.07
-320	T	145.3	171.8	3.0	187.0	1.09
78	L	96.9	120.4	7.5	135.8	1.13
78	T	98.4	122.0	6.0	141.3	1.16
800	L	71.9	84.0	7.2	91.0	1.08
800	T	74.0	84.6	4.9	94.6	1.11

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DMIC Memorandum Number	Title
165	Review of Uses for Depleted Uranium and Nonenergy Uses for Natural Uranium, February 1, 1963
166	Literature Survey on the Effect of Sonic and Ultrasonic Vibrations in Controlling Grain Size During Solidification of Steel Ingots and Weldments, May 15, 1963
167	Notes on Large-Size Furnaces for Heat Treating Metal Assemblies, May 24, 1963 (A Revision of DMIC Memo 63)
168	Some Observations on the Arc Melting of Tungsten, May 31, 1963
169	Weldability Studies of Three Commercial Columbium-Base Alloys, June 17, 1963
170	Creep of Columbium Alloys, June 24, 1963
171	A Tabulation of Designations, Properties, and Treatments of Titanium and Titanium Alloys, July 15, 1963
172	Production Problems Associated with Coating Refractory Metal Hardware for Aerospace Vehicles, July 26, 1963
173	Reactivity of Titanium with Gaseous N_2O_4 Under Conditions of Tensile Rupture, August 1, 1963
174	Some Design Aspects of Fracture in Flat Sheet Specimens and Cylindrical Pressure Vessels, August 9, 1963
175	Consideration of Steels with Over 150,000 psi Yield Strength for Deep-Submergence Hulls, August 16, 1963
176	Preparation and Properties of Fiber-Reinforced Structural Materials, August 22, 1963
177	Designations of Alloys for Aircraft and Missiles, September 4, 1963
178	Some Observations on the Distribution of Stress in the Vicinity of a Crack in the Center of a Plate, September 18, 1963
179	Short-Time Tensile Properties of the Co-20Cr-15W-10Ni Cobalt-Base Alloy, September 27, 1963
180	The Problem of Hydrogen in Steel, October 1, 1963